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## PATENT SPECIFICATION



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### COMPLETE SPECIFICATION

#### Improvements in or relating to Apparatus for making Flat Metallic Products

I, JOSEPH MARCEL MERLE, a citizen of the French Republic, of 1212, Carlisle Street, Tarentum, Pennsylvania, United States of America, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

This invention relates to the production of flat metallic products in strip form produced direct from molten metal.

There have been numerous attempts to form flat metallic products direct from molten metal, but all such attempts have either resulted in complete failure or have resulted in procedures of doubtful commercial practicability, both from the standpoint of the procedure itself and also from the standpoint of the product resulting therefrom.

One such procedure was suggested as early as 1865 by Bessemer and, involves providing a pool of molten metal in the crotch between two cooled rolls and rotating the rolls in opposite directions and in such a way as to discharge downwardly and through the space between the rolls, such solidified metal as may form within the pool and to mechanically deform it into a flat product as it is so discharged. Variations of this procedure have been periodically attempted, but the commercial art discloses that such attempts have only met with mediocre success and then in connection with metals of low melting points.

The object of the invention is to take advantage of natural physical phenomena or laws not heretofore utilized in previous attempts to form sheet or strip-like material direct from molten metal, and as a result I not only produce a product having highly advantageous and novel physical characteristics, but I also produce a procedure which is simple and effective and is capable of being effectively employed commercially.

A metal in the molten state acts like most other liquids. It exhibits the physical characteristic of surface tension in varying degrees and dependent somewhat upon the particular metal and its

temperature, but its principal characteristics, at ordinary industrial pouring temperatures, are its liquid-like free mobility resulting from the reduced cohesive force between its atomic or molecular constituents; its ability to readily shape itself in response to applied or confining forces; its ability to wet most materials with which it is brought into contact; and its self-leveling characteristic under uniformly applied forces such as gravity or other directional forces. The invention takes advantage of such inherent physical characteristics as are exhibited by molten metal at ordinary industrial pouring temperatures and involves utilizing those characteristics.

The invention involves the manufacture of flat metallic products by discharging molten metal as a stream, converting the same into a strip, rapidly undercooling said strip substantially uniformly throughout its entire cross section down to a metastable state at a predetermined temperature below but close to the freezing point of the metal and causing the strip to crystallize spontaneously throughout from said metastable state. In accordance with the invention, in such manufacture, apparatus is used comprising the combination of means for discharging said molten metal as a stream, means for converting the same into a strip, means for undercooling the same to said predetermined temperature and for causing the strip to crystallize spontaneously.

The apparatus of the invention broadly results in creating a controlled flow of molten metal existing at a predetermined temperature, such, for example, as the ordinary industrial pouring temperature, and in intercepting the flow with an extended, clean, cold surface of a heat absorbing agent capable of being wet by the molten metal and moving at a uniform rate in the direction of its extended surface and at a velocity greater than the velocity of flow of the metal, whereby the molten metal is, in effect, delivered to the moving surface, coats

[Price 1/-]

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that surface or a portion thereof by reason of its wetting action, i.e., its capacity to adhere to such surface, and builds up a layer thickness thereon in response to interatomic or intramolecular forces—i.e., cohesion forces—and to an extent which is dependent upon the relative velocity of the heat absorbing surface and the velocity of flow of the molten metal stream, and then chilling the metal of this layer to the solid state while it is in contact with and in fact supported by the surface of such heat absorbing element.

Owing to the rapid withdrawal of heat from a comparatively thin layer of metal there is a practically uniform cooling throughout the entire cross-section. The metastable state occurs practically simultaneously throughout the entire cross-section and crystallization is so rapid that it is practically instantaneous as no one part of the cross section is cooled to such a temperature that the undercooled metal will solidify before the whole cross section reaches this temperature.

My invention also involves continuously producing strip from molten metal, such as steel, by creating a substantially uniform flow of molten metal in the form of a confined stream; laying such stream on a substantially horizontally disposed, rapidly moving heat absorbing surface capable of being wet by the molten metal; accomplishing the delivery of the molten metal to such surface so as to eliminate the effect of the turbulence in the stream at the point of initial contact between molten metal and heat absorbing surface; and accumulating on such surface a molten layer by reason of the cohesive and adhesive forces there involved, cooling the layer so formed below the solidification temperature and then delivering the layer in the form of a continuous strip while utilizing the contractive and expansive force encountered to free it from the heat absorbing element.

I have discovered that where molten metal such, for example, as ferrous metal, is so delivered to such a surface the quiescent stream continuously supplied onto the moving surface will be drawn out into a layer moving at the velocity of the surface and accumulated by combined adhesive and cohesive forces from metal below the major portion of the surface of such stream. The metal of the layer is self-leveling hydrostatically while still molten and highly plastic but is rapidly chilled by reason of its extended surface, and is converted into a solid strip of substantially uniform width and thickness which is first carried by the heat absorbing surface by reason of the gripping

contact between it and the surface, but which shrinks as it cools and is thus freed from the supporting and cooling surface without any interfering factors.

The width of the strip so formed can be controlled by controlling the width of the molten metal stream as it is delivered to the heat absorbing surface and I have discovered that the thickness of the strip may be controlled within close limits by controlling the relationship between the velocity of the heat absorbing surface and the velocity of flow of the molten stream delivered thereto. To state this in another way, the cross section of the metal strip is determined and controlled within close limits, by the following relation: Cross Sectional area of the strip multiplied by the velocity of the heat absorbing surface equals the cross sectional area of the molten stream (delivered to the surface) multiplied by the velocity of the flow of that stream.

For example, if the stream of molten metal flowing from a rectangular nozzle 2 inches wide and one-half inch thick, and at a velocity of two feet per second is delivered to and laid upon a heat absorbing surface, such as previously described, moving at 50 feet per second, the section of the resulting continuous strip can be

computed as follows:  $2 \times \frac{1}{2} \times \frac{2}{50} = .04$

square inches. That is to say, the metal layer or strip formed will have a cross sectional area of 0.04 square inches. I have also discovered that where a nozzle, such as above described, delivers molten metal to such a heat absorbing surface under conditions such that there is little or no turbulence at the zone of initial contact between the stream and the heat absorbing surface, the width of the resulting layer and strip will be substantially that of the nozzle, consequently in the above example the gage of the strip or film will be .04 divided by 2 or .020 inches.

While the procedure for forming the continuous strip may be varied, it will be apparent from the foregoing that the now preferred procedure not only involves the utilization of all the forces heretofore enumerated, but also selecting a heat absorbing surface which is wetted by the particular molten metal acted upon. It may be that further investigation will disclose variations in the capacity of a molten metal to wet different solid materials, but I have found that most molten metals, including alloys, when delivered to a clean, cold, dry surface of solid metal, such as steel or copper or a copper alloy, provide good contact be-

tween the molten metal and the surface due, no doubt, to the wetting action or the free action of interatomic attraction between the metal of the heat absorbing surface and the molten metal delivered thereto. This force is of considerable magnitude, even though other forces may be involved, and can account for the fact that the molten layer adheres to the moving heat absorbing surface and acts as a unitary part of that surface—i.e., moving with it at the same speed and in the same direction—up to the point where it loses the adhesive and vacuum grip by its complete solidification and subsequent shrinkage under the cooling or chilling conditions encountered.

It will, of course, be apparent that even after the metal strip is thus freed from the moving heat absorbing surface it will continue to move in the direction of and in response to the impelling forces previously acting on it and to friction.

While the layer of molten metal is adhering to and moving with the heat absorbing surface, the absolute contact between the metal and the surface makes it possible to consider the two as a single bi-metallic section in determining heat exchange conditions. The heat exchange between the molten layer and the solid or heat absorbing layer and throughout their respective thicknesses is directly proportional to the heat conductivity of each layer and the heat gradient involved, consequently the above known factors make it possible to determine the length of time that contact must be maintained between the two layers in order to solidify the molten layer and free it from the heat absorbing layer. That is to say, the heat transfer which takes place is between a selected and controlled molten metallic layer and a determined section of a selected heat absorbing material, consequently the desired velocity of the heat absorbing surface having been selected, the distance through which the combined or bi-metallic section must move—in order to obtain the desired cooling of the molten metal layer—can be mathematically determined.

While I have stated that the thickness of the molten metal layer, and consequently of the finished strip, can, in effect, be controlled by controlling the relationship between the velocity of the moving surface and the velocity of flow of the molten stream delivered to that surface, this statement is accurate only, so far as I now know, for thickness up to about  $\frac{1}{4}$ ", as other factors may affect the exact relationship when molten metal layers of larger thickness are involved. The foregoing, however, discloses that the known

factors available make it possible to accurately determine the amount and rate of heat dissipation necessary in order to accomplish the desired results, and that the various facilities open to the designer make it possible to not only effectively dissipate the heat of the molten metal, but also to so dissipate it as to avoid the disadvantages of surface pitting, cracking erosion, warping or other objectionable distortion of the heat absorbing element. It, therefore, follows that the heat absorbing element can be so designed—from the standpoint of its composition, its form and its cooling facilities—as to absolutely avoid any possibility of the molten metal welding or sticking permanently thereto, with the result that good surface conditions of the finished strip can be substantially assured and even though further processing is not resorted to.

I have discovered that where the heat absorbing element is properly selected, with relation to the capacity of the molten metal to wet it, the contact between the molten metal and the supporting surface of the heat absorbing element is so intimate that a vacuum grip is accomplished and the surface of the heat absorbing element is, in effect, reproduced upon the formed strip. For this reason it is not only possible but desirable to provide the heat absorbing element with a polished heat absorbing surface and then to correlate heat input and heat dissipation from that surface so as to avoid rise which will even tend to corrode or mar it.

The invention also results in the production of a strip having improved physical characteristics. It is apparent from the foregoing description that the invention involves dissipating the superheat of fusion and an amount of heat equal to all or most of the latent heat of fusion—while the metal being processed is in layer-like form of the thickness of the finished product. As the moving heat-absorbing surface contacts with the molten metal, it almost instantaneously draws that metal out into a thin sheet of the desired finished thickness and, as a result, substantially all the cooling takes place under conditions such that heat is not only rapidly delivered to the relatively cold heat-absorbing element but also while the metal, being so cooled, exists in layer-like form.

It is generally acknowledged that the cast structure of metals is weak as compared to such structure as is developed by or resulting from mechanical working, and that this inherent weakness is due to the typical crystal formation obtaining in a cast product which has zones or layers of crystallization as follows:

1. A chilled layer or skin at the periphery of the casting and made up of small stringer-like at random (not oriented) crystals.

5 2. A layer of long columnar crystals also called dendrites or needles, oriented with respect to the axis of crystalline growth and in a direction of the heat flow and which is the main cause of the cast  
10 structural weakness.

3. A central zone of equiaxed large crystals.

The physical properties of the above mentioned chilled layer are usually much  
15 better than the properties of other parts of the casting and of the finished product after the casting has been subjected to mechanical working, because its chemical composition is homogeneous and free of  
20 segregation and in this respect is the same as the molten metal in the furnace or ladle. On the other hand, the heterogeneous crystalline structure of the casting is characterized by selective segregation  
25 of the alloy and impurities, gas pockets, shrinkage cavities or piping and other well known phenomena defined under the general name of ingotism.

Recent research and investigation, in  
30 connection with the crystallization of metals, has shown that the at random, fine crystalline structure of the chilled layer of an ingot is due to the substantially instantaneous undercooling of a  
35 thin shell of molten metal as it contacts with the cold walls of the mold, and the resultant, practically, spontaneous crystallization within that shell which is free from segregation and orientation. It  
40 has been found that the section of the crystals in the chilled layer becomes smaller as the velocity of crystallization increases—i.e., as the time factor decreases. I not only utilize these discoveries  
45 in producing the product here defined but also in controlling the size of such crystals and the relative fineness of the material.

From the foregoing it will be apparent  
50 that the whole metal product of the invention is similar in physical characteristics to the chilled layer of an ingot and is characterized by a special new primary crystal structure free from separate or  
55 distinct zones or layers of crystallization and homogeneous and uniform throughout the length and thickness of the strip. That is to say, said product is characterized by minute stringer-like crystals at  
60 random, and all substantially identical in size and uniformly and homogeneously distributed throughout the mass of the finished product. In addition, the strip-like product is characterized by a uniformity of chemical composition identical

to that of the molten metal supplied by the melting furnace and free from variations and defects, such as are inherited from a primary ingot structure and as  
70 are occasioned by selective segregation of component metals and concentration of impurities at the grain boundaries of columnar crystals, gas pockets, and the like.

The material is also free from the  
75 directional effect such as is ordinarily occasioned by mechanical working and crushing of the large dendritic crystals which characterize ingot and other cast formations. This new product, however,  
80 retains most of the above-described characteristics and advantages of its new primary crystalline structure after mechanical working, such as rolling, forging or extrusion and after heat treatment to which it responds effectively and  
85 actively, due to its uniformity and homogeneity.

This crystalline structure of this improved product and the physical properties resulting therefrom are particularly  
90 marked in high alloys, such as high speed tool steels, and the so called stainless irons and steels. In addition, it will be apparent that the procedure is such as to  
95 eliminate almost wholly defects and disadvantages occasioned by gases occluded or in solution in the molten metal.

In order that the invention may be fully understood, it will now be described with  
100 reference to the accompanying drawings.

In the drawings, Figure 1 is a diagrammatic vertical sectional view of a machine for carrying out the invention and in  
105 which the molten metal is delivered to the surfaces of a rapidly moving heat absorbing element in the form of an endless belt;

Fig. 2 is a vertical sectional view, on an enlarged scale, and illustrates a  
110 modification of a structural detail of the machine shown in Fig. 1;

Fig. 3 is a view corresponding to Fig. 2 but diagrammatically illustrating a  
115 forming roll in such relationship to the associated parts that it coacts with the heat absorbing element in the production of the finished product;

Fig. 4 is a diagrammatic, sectional view of a modified form of apparatus in which  
120 the heat absorbing element is in the form of a rigid annulus, such as a ring or cylinder;

Fig. 5 is a diagrammatic, fragmental, sectional view of a machine similar to the  
125 machine of Fig. 4 but illustrating structural variations;

Fig. 6 is a side elevation of an apparatus generally similar to that illustrated  
130 in Fig. 4 or Fig. 5;

Fig. 7 is a fragmental, sectional view of a machine, such as is illustrated in Fig. 11, but equipped with a rotary metering valve;

5 Fig. 8 is a view in side and sectional elevation of a ring type machine equipped with structural features similar to those illustrated in preceding views;

10 Fig. 9 is a diagrammatic view illustrating the gearing employed in connection with the machine of Fig. 8;

Fig. 10 is a fragmental, transverse, sectional view of a water-jacketed strip-forming ring and illustrates means for 15 driving the ring;

Fig. 11 is a vertical, sectional view of the machine diagrammatically illustrated in Fig. 8;

20 Fig. 12 is a diagrammatic top plan view of the machine shown in Fig. 8;

Fig. 13 is a diagrammatic, fragmental, sectional view of apparatus such as disclosed in Fig. 8 and illustrates accessories which may be employed in connection 25 therewith;

Fig. 14 is a plan view of an apparatus adapted to produce, in accordance with this invention, a bimetallic strip composed of two layers bonded together in side by 30 side relationship;

Fig. 14a is a sectional view through the strip formed in the apparatus of Fig. 14;

35 Fig. 15 is a vertical sectional view of a fragment of a modified form of apparatus which is adapted to produce a bimetallic strip composed of a plurality of layers inseparably bonded together in super-imposed relationship;

40 Fig. 16 is a fragmentary perspective view of a modified form of bimetallic strip adapted to be produced by an apparatus similar to that of Fig. 15;

45 Fig. 17 is a view partly in vertical section and partly in elevation of an apparatus adapted to form a ply metal strip-like product from a solid metal strip and a molten metal stream; and

50 Figs. 18 and 19 are reproductions of photomicrographs at different magnifications of the microstructure of products produced in accordance with my present invention.

55 Fig. 1 is a diagrammatic illustration of a simple but effective machine for carrying out the invention. There the heat absorbing agent is in the form of an endless belt or band, preferably made from metal having high heat conductivity, such, for example, as copper, silver, copper alloy, bronze, or aluminium. The 60 belt is so mounted that one strand or reach is not only substantially horizontal, but is also substantially flat and is adapted to receive molten metal delivered 65 from an associated nozzle. The arrange-

ment is also such that a stream of molten metal of controlled width, flow and temperature is, in effect, laid upon the belt while the belt is moving at a uniform rate 70 in the general direction of stream flow and at a velocity such that the stream is drawn out into a layer of the desired thickness of the finished product. The continuous stream of metal is so laid upon the moving 75 belt as to substantially eliminate turbulence but at the same time create a continuous and controlled flow on the belt so that the finished product can be produced in continuous or strip-like form.

The heat absorbing belt is so constructed with relation to heat absorbing 80 ability and is so positioned, with relation to the molten metal delivery nozzle, and is so cooled that it is capable of chilling the metal contacting therewith to the 85 solidification temperature while such metal is retained flat, and all without raising the temperature of the belt above a safe and predetermined temperature. That is to say, the belt is so constructed 90 and proportioned with relation to its heat absorbing capacity and available cooling facilities that the temperature thereof is never raised to such a point as to occasion welding, surface pitting, cracking or 95 erosion, or the warping of the belt. In addition, the belt and its supports are so positioned, relatively to the molten metal delivery nozzle, that the time of contact between each portion of the belt and the 100 metal supported thereby is sufficient not only to insure solidification of the molten metal, but also its free release from the belt under such conditions that it will be propelled, by the forces previously acting 105 on it, in substantially the direction of its travel while in gripping contact with the belt.

Referring specifically to Fig. 1, a heat absorbing element 1, in the form of an 110 endless belt, is mounted on spaced pulleys 2 and 3, which are suitably journaled on a frame 4 including a table 4a. The pulleys 2 and 3 are so located, with relation to each other, that the upper 115 reach or leg of the belt is substantially horizontal and is located immediately above the table 4a. A nozzle 5, for delivering molten metal onto the upper reach of the belt, is shown formed as a 120 part of a molten metal receptacle 6, which is mounted on the machine frame and is adjustable therealong and lengthwise of the upper reach of the belt 1.

Any suitable means may be employed 125 for driving the belt, consequently, I merely note that the pulley 2 is mounted on shaft 7 and that the shaft 7 is a driving shaft which may be, and preferably is, rotated by a motor, the speed of which 130

may be adjusted. In order to maintain the upper reach of the belt horizontal and also flat, i.e., substantially in one plane, I employ means for taking up the slack in the belt and this means is illustrated as a hydraulic cylinder 8 carried by the frame 4 and provided with a piston 9 operatively connected to the bearing block of the pulley 3. The cylinder is shown as provided with an inlet port 10 through which liquid under pressure is admitted. In addition to this yielding means for taking up the slack in the belt, I also provide grooved guides 11 mounted on the machine frame and each adapted to receive one lateral edge of the upper reach of the belt 1 as the belt leaves the pulley 3 and moves across the table 4a and onto the pulley 2.

As shown, the delivery end of the nozzle 5 is located immediately above the upper reach of the belt and at a point intermediate the pulleys 2 and 3. The receptacle 6 is shown as provided with a refractory lining and is divided into two compartments 12 and 13, which communicate with each other through a continuously submerged port 14. The compartment 13 communicates directly with the nozzle 5 and is preferably of substantially greater capacity than the compartment 12, which is adapted to receive molten metal direct from a furnace or ladle. In the drawings, I have shown a diagrammatic representation of a ladle 15 so suspended that its pouring apparatus 16 is delivering molten metal into the compartment 12. With this arrangement, slag and other impurities tend to float to the top of the metal within the compartment 12, whereas clean metal enters the compartment 13 through the submerged port 14 and is available for delivery through the nozzle 5.

The belt 1 is so driven by the pulley 2 that it moves in the direction of the arrows of Fig. 1 and its upper reach, therefore, moves in the general direction of the flow of metal through the nozzle 5 and onto it.

Various means may be employed for cooling the belt 1 and in the drawings I have illustrated means for spraying cooling medium, such as liquid, onto the lower leg or reach of the belt. As there illustrated, the cooling means includes a liquid delivery pipe 17, which communicates with and supplies cooling medium to spray pipes 18, which extend along and below the lower reach of the belt and are provided with spray apertures for directing cooling medium on the lower surface of the belt. One or more rubber squeegees 19 are so mounted on the machine frame that they bear on the belt 1 at a point beyond the delivery of coolant thereto so

that all traces of coolant are wiped off of the surface of the belt as it moves toward and onto the pulley 3. As shown, the squeegees are located within the confines of a tank 20, which extends throughout the length of the belt, is located below the spray pipes 18 and is adapted to receive the coolant issuing therefrom and dripping from the belt. The tank is provided with a drain port 20' and if desired ordinary and well known means may be employed for recirculating the coolant collected within the tank 20.

In Fig. 1 I have shown the machine provided with a product-receiving table 21 and an extension thereof in the form of an arm 22, which is hinged on the machine frame in such position that its free end may bear on the belt 1 as it moves around the pulley 2. In addition, the arm 22 is so formed that its upper face—i.e., its product-receiving and directing face—lies within or just below the plane defined by the upper reach of the belt.

I have also shown the apparatus of Fig. 1 as provided with a protective hood 23 for the purpose of preventing oxidation of the molten metal as it is delivered onto and moves with the belt 1. As there illustrated, the hood is in the form of a shield which encloses a portion of the upper reach of the belt and which is secured to the receptacle 6 or the portion thereof which defines the nozzle 5. The hood is provided with a gas delivery pipe 24 and may be provided with a gas discharge pipe 25. That is to say, the arrangement is such that an inert atmosphere may be maintained within the hood by reason of the delivery thereto of an inert gas, such as hydrogen, nitrogen, or ammonia gas.

The adjustment of the receptacle 6 along the belt may be accomplished in a number of more or less obvious ways and for this reason I have diagrammatically illustrated it as associated with an ordinary positioning screw 26, which is threaded through a fixed or stationary bracket 26' of the machine frame. Such an arrangement provides means for adjusting the position of the nozzle 5 along the upper reach of the belt and for locking it in the adjusted position.

The operation of apparatus such as described is as follows: Molten metal at a temperature, such as is ordinarily employed in commercial pouring, is delivered to the compartment 12 of the receptacle 6 and preferably under conditions such as to maintain a predetermined level within that compartment. This metal passes through the submerged port 14 into the compartment 13, which, as stated, is in open communication with the nozzle 5. 130



The compartment 13 is preferably of such capacity as to minimize the effect of such variations in head as may be occasioned by a lack of uniformity in the delivery of metal to the compartment 12.

The nozzle 5 is so formed and located that the stream of molten metal issuing therefrom is delivered to the surface of the upper reach of the belt without producing undue turbulence in the flow of metal onto the surface. In addition, the stream so delivered is controlled as to width and rate of flow. The width substantially corresponds to that of the nozzle and the flow responds to variations in head within compartment 13, i.e., the cross sectional area of the nozzle 5 and head of molten metal within the compartment 13 controls the velocity of flow of the molten metal issuing from the nozzle and moving onto the belt.

The foregoing discloses that the belt 1 is so driven that its upper reach is moving in the general direction of the metal flow during the entire period that metal is issuing from the nozzle 5. It will also be apparent that the velocity of the belt is such, with relation to the rate of metal flow onto it, as to draw that flow out into a layer of predetermined width and thickness, i.e., the width and thickness of the finished product.

One problem with apparatus, such as illustrated in Fig. 1, is to so position the nozzle 5 with relation to the upper reach of the belt 1 that the layer of metal distributed over the belt is not only cooled to the solidification temperature, but also to such an extent that it is freed from the belt prior to the time that the belt moves around the pulley 2. This, however, can be computed with sufficient accuracy to assure the desired results. Assume, for example, that the machine of Fig. 1 is operating under conditions such as to produce a finished product the form of a strip 2" wide and .020" thick and that the delivery throat of the nozzle 5 is 2"  $\times$   $\frac{1}{2}$ " and delivers molten metal to the belt 1 at the rate of 2 feet per second. The application of the previously mentioned mathematical equation discloses that the belt must be driven at a speed such that its linear velocity is 50 feet per second. This also means that the layer of molten metal (2" wide and .020" thick) adhering to the belt is moving at a velocity of 50 feet per second. The designer's specific problem is, therefore, to so design the belt 1—from the standpoint of material employed in its make-up, its length and also cooling facilities available—that the metal supported on it is cooled to the desired temperature as it moves toward the pulley 2, and all with-

out raising the belt or any portion thereof to such a temperature as will permit welding or as will detrimentally affect the physical characteristics of the belt.

The man skilled in the art will recognize that the conditions above stated define the quantity of heat to be extracted from the molten metal and the outside time limitation in which the extraction must be accomplished and he can, therefore, determine the dimensional requirements of the heat absorbing belt necessary to accomplish the above result. The man skilled in the art will also recognize that the dimensions of the belt must be such as to dissipate the heat thus taken up by the belt, and to accomplish the dissipation during the period that the belt is moving free of the molten metal or the finished product and this factor designates the length of the belt. That is to say, the belt 1 must be so designed that it will accommodate the rapid dissipation of heat from the molten metal delivered to it but it must also be so designed that each unit of length thereof will, under the cooling facilities available, be cooled to a predetermined and constant temperature during the time it is moving free of molten or solidified metal. In other words, the belt must be so designed that each unit of length thereof will be cooled to a predetermined temperature as it moves around the pulley 2, throughout the distance spanned by the lower reach of the belt, around the pulley 3 and back to the metal-receiving position below the nozzle 5.

From the foregoing it will be apparent that the calculations referred to will designate the thickness of the heat absorbing belt. The engineer will, therefore, recognize that this thickness and the physical characteristics of the metal, of which the belt is made, will determine the diameters of the pulleys 2 and 3 in order to avoid subjecting the belt to stresses beyond the elastic limit as it moves around the pulleys. It should, however, be noted that the diameter of the pulleys 2 and 3, or of equivalent structures, have no other influence on the working of the process here outlined, except where their belt supporting faces are so subjected to a coolant that they perform an important part in absorbing heat from the belt.

From the foregoing it will be apparent that molten metal delivered to the upper reach of the belt 1, under the condition above assumed, will be chilled to substantially its final temperature as it moves through the length designated by X in Fig. 1. This length is variable and depends upon the final or delivery temperature of the product, the initial temperature of the molten metal and the heat

conducting conditions involved. It will also be apparent to those skilled in the art that under some conditions the majority of such length is required for the purpose of cooling the metal to final temperature after it has arrived at the solidification temperature, i.e., a temperature such that the metal is no longer in the liquid state.

I have heretofore stressed the necessity for maintaining the belt flat as it receives, forms and chills the molten metal. This is because I consider that the molten metal is, in effect, subjected to forming forces by the heat absorbing element, but must be cooled through the plastic range and into the solidification range without being subjected to disrupting forces. For this reason it is necessary to so form and mount the pulleys 2 and 3 that during the operation of the process the molten-metal-receiving reach of the belt moves without vibration and under such conditions that its metal supporting surface moves in a plane defined by the direction of its motion, while passing through length X, or such portion of such length as is required to accomplish the solidification of the molten metal.

As previously stated, the contact between the molten metal and the heat absorbing element is so intimate that the surface characteristics of the element are reproduced on the adjacent face of the finished strip-like product. Under some conditions it may, therefore, be desirable to provide the heat absorbing element with a polished surface and conditions may also make it desirable to plate the surface of the element with a metal having high heat conductivity or other desirable physical characteristics. For example, where conditions are such as to make it desirable to provide a heat absorbing element having a surface of high melting point, highly resistant to erosion and to liquid diffusion, the heat absorbing element may be plated with such a metal as chromium and then polished to the desired degree of smoothness. On the other hand, where conditions are such as to indicate the necessity for high heat conductivity at the surface of the heat absorbing element, that element may then be plated with such metal as silver. For this reason one detail of my invention involves providing the heat absorbing element with a surface such as conditions designate and even where such a surface is laid onto the element by a plating or other procedure.

The strip-like product produced, as above described, is chilled to such a temperature that it frees itself from the belt without disrupting or disturbing

factors, prior to arriving at a position with relation to the pulley 2, where the belt contacts with and starts to move around that pulley. The strip-like product will, therefore, move across the extension 22 and onto the table 21 from which it may be delivered to a coiler or to other means for handling it.

Where the hood 23 is employed, gas is delivered thereto through the passage 24 during the entire product-forming operation. Ordinarily, gas is selected so as to provide a neutral or inert atmosphere, but the gas may be selected in order to promote a desired chemical reaction with the molten metal. Under such circumstances, a constant circulation of the gas is preferably maintained within the hood in order to insure continual effectiveness in connection with the desired reaction and the passage 25 may therefore be employed as a part of the gas circulating system.

In Fig. 2 I have shown a modified form of molten metal receptacle equipped with accessories which may be employed in a machine, such as illustrated in Fig. 1. As shown, the receptacle 6<sup>1</sup> is provided with two compartments 12<sup>1</sup> and 13<sup>1</sup>, which are adapted to be placed in communication with each other through a submerged port 14<sup>1</sup>. This port is provided in a horizontally disposed partition and is adapted to be controlled by a manually adjustable stopper 27. With such apparatus, flow through the nozzle 5<sup>1</sup> can be controlled by adjusting the position of the stopper 27 with relation to its seat around the port 14<sup>1</sup>, or the flow can be completely cut off by seating the stopper and thus closing the port 14<sup>1</sup>.

The previous description discloses that the molten metal delivered through the nozzle is drawn out into a metal stream or layer by the movement of the belt 1 and that the uniformity of this layer depends, at least in part, upon uniformity of flow of the molten metal stream issuing from the nozzle 5<sup>1</sup>.

It is, of course, apparent that the velocity of such flow will vary with variations in the gravity head, and it will also be apparent that the confining walls of the nozzle and of the passage leading thereto, will cause retardation of the flow in the portions of the stream immediately adjacent thereto. In order to insure a flow of metal onto the belt which is substantially uniform throughout all portions of the stream, I have provided what may be termed a metering valve 28, which is diagrammatically shown in Fig. 2 as journaled in an adjustable support 29 carried by a bracket 30 of the receptacle 6<sup>1</sup>. This metering valve is



cylindrical, is so formed that a coolant may be delivered to the interior thereof, and is adapted to be driven at such a speed that it will have an impelling effect on the molten metal issuing from the receptacle 6<sup>1</sup> and will, therefore, tend to minimize the variations in velocity which may be occasioned by the fractional resistance and slight variations in gravity head.

In the apparatus illustrated, the valve 28 is so located that it cooperates with the associated stationary walls in forming the throat of the nozzle 5<sup>1</sup>. In this connection it will be understood that the stationary walls referred to provide a channel-shaped passage into which the cylindrical valve 20 so fits that its cylindrical surface supplements the channel-shaped passage in forming the nozzle.

Any suitable means may be employed for rotating the valve 28 at a uniform but adjustable speed and in the drawings I have diagrammatically illustrated a chain and sprocket drive in such a way as to indicate that the valve 28 may be and preferably is driven by the belt drive. It will be understood that means may be employed for varying the rotational speed of the valve and thus varying the impelling force on the molten metal traversing the nozzle and that independent means may be employed for driving the valve. In addition to varying the impelling force, the valve 28 functions as a valve in that it may be employed to vary the sectional area of the throat of the nozzle. In order to accomplish this I have shown the valve support 29 projecting into a guiding aperture 32, with which the bracket 30 is provided, and I have diagrammatically illustrated a screw connection 33 between the support and the bracket and so arranged as to adjust the position of the support with relation to the guiding aperture 32.

In the drawings I have shown a contact strip 34 carried by a suitably slotted bracket 34<sup>1</sup> of the receptacle 6<sup>1</sup> and yieldingly pressed against the cylindrical surface of the valve 28. This strip is in such a position that it provides a seal between the valve and the bracket 34 and thus aids in confining the molten metal as it moves toward the throat of the nozzle 5<sup>1</sup> under the effective gravity head.

The cylindrical valve 28 can be made of refractory material or of a heat resisting alloy which will withstand the corrosive and/or erosive action of the molten metal. It may, however, be made of steel or of any suitable material having the desired heat conducting characteristics and when made from such material it will preferably be provided with an

internal passage 28<sup>1</sup> for cooling water or other cooling medium. It will, of course, be understood that the passage 28<sup>1</sup> is provided with inlet and outlet ports so located that the cooling medium can be readily circulated therethrough while the valve 28 is rotating.

From the foregoing it is apparent that the metering valve provides two methods of controlling the flow from the nozzle 5<sup>1</sup>; one depending on the propelling effect of the valve and rendered effective by varying the speed of its rotation; and the other depending on the position of the valve. While variations in the speed of rotation of the valve cause variations in the rate of flow through the nozzle, the primary purpose of rotating the valve is to assure, as far as possible, a uniform flow of the nozzle and the parts of the stream issuing therefrom.

A stream of molten metal issuing from the nozzle, contacts with the belt 1 (generally moving at a higher velocity than the velocity of flow of the metal), instantly wets the belt, adheres to it and is carried by it in a film-like layer 35, which is self-leveling hydrostatically and which is of uniform section and of a thickness depending upon the relative velocity of the belt and the rate of metal flow onto the belt. This layer, when chilled below the solidification temperature, constitutes the finished product.

In Fig. 3 I have diagrammatically illustrated a still further modification of the apparatus of Fig. 1. In addition to employing the metering valve 28, described in connection with Fig. 2, I also employ a forming roll 36, which is mounted on a drive shaft 38 and is adjustable toward and away from the nozzle, i.e., is capable of being adjustably positioned longitudinally of the belt. This forming roll is preferably driven at such a speed that its peripheral velocity equals that of the belt 1. The roll can be made of refractory material or of a heat resisting alloy or an alloy having high heat conductivity characteristics, in which latter event it will be provided with an interior passage 36<sup>1</sup> for coolant so supplied and so circulated through the interior passage as to completely dissipate the heat taken up by each portion of the roll contacting with the hot metal carried by the belt, and prior to the time that that portion of the roll again contacts with such metal.

The position of the roll longitudinally of belt 1, i.e., its position with relation to the point of initial contact of the molten metal with the belt, may be varied depending upon the specific result desired. For example, where the molten

metal delivered to the belt is characterized as a gas carrying metal, such as effervescent steel or a brass, the gas will be given off when the solid phase is precipitated and the point of this occurrence, in the movement of the belt, can be mathematically calculated within very close limits. It will, therefore, be possible to so set the roll 36 that it will not only compress or reduce the thickness of the plastic metal layer carried by the belt, but accomplish this reduction at such a point along the belt (and therefore at such time during the cooling process) as to assist in the forcing out or the liberating of the gases carried by the metal. Thus the roll 36 may be so adjusted, with relation to the direction of the belt travel and also with relation to its position above the belt, that it will effect a hot working of the metal and at such a point as to aid in liberating gases from the metal. The resultant product will be rendered more homogeneous by such a functioning of the roll and will be substantially free of gas pockets and blow holes.

Then too, the roll 36 may be set so close to the molten metal delivery nozzle that the metal issuing from the nozzle and carried by the belt will still be in molten condition when contacted by the roll surface. Under such conditions, the metal will wet the roll surface, will shape itself to the contour of the roll while under it, will deliver a substantial quantity of heat to the roll while thus in contact with it, but will not adhere to the roll because of the centrifugal force occasioned by the high rotative speed of the roll. That is to say, the roll may be positioned that it will act on the metal carried by the belt while the portion of such metal contacting with it is still molten, but even so, the roll may be so employed as to impart surface characteristics, to the upper surface of the metal film or layer carried by the belt and to some extent shape and define the thickness of such layer. It will be apparent that the heat absorbing characteristics of the roll are of primary importance in accomplishing the results here defined.

From the foregoing it will be apparent that the position of the roll 36, with relation to the point of initial contact of the molten metal with the belt 1, will determine the functioning of the roll, but that in any event, the roll will tend to impart surface characteristics to the finished product and will also play a part in determining the thickness of the finished product. It will, of course, be apparent that Fig. 3 is employed for descriptive purposes only and that in

order to render the roll 36 effective, particularly as an instrument of hot working, the belt 1 will necessarily have to be backed at a point opposite to it in order to effectively counteract the force imparted to the metal layer by it. This backing can be most effectively accomplished by means of supporting rolls or rollers.

Figs. 4 and 5 are diagrammatic sectional views of apparatus which may be employed in carrying out the manufacture of strip or sheet-like material and in which the substantially flat heat absorbing surface, resulting from the use of an endless belt or band, is replaced by a cylindrical surface of a rigid annulus. In Fig. 4 I have shown in section an assembly of elements, including a source of molten metal, such as the ladle 15, a receptacle for such metal, such as the receptacle 6, and a rigid annulus 40, which is provided with a strongly cooled heat absorbing surface 41, onto which molten metal is delivered by the nozzle 5, forming a part of the receptacle 6. The annulus 40 is shown broken away for convenience of illustration and is shown as suspended on driving roll 44, the axis of which is located within the vertical plane defined by the geometric and rotational axis of the annulus. In this respect the view is illustrative only and is intended to disclose that the annulus is so mounted and so driven that it is free to expand in all directions.

While various means may be employed for cooling the heat absorbing portion 40 and its surface 41, I have shown the annulus as provided with cooling chamber 42, formed between the annulus 40 and an annular jacket 40<sup>1</sup> and through which an intensive circulation of water or other coolant may be maintained. I have also disclosed the apparatus as provided with a protective hood 23<sup>1</sup>, which corresponds in structure and function to the hood 23 of Fig. 1.

If a stream of molten material, such as molten metal, is laid upon a curved cylindrical surface, such as the surface 41 of the annulus 40, and the annulus is rotated, about its geometric and gravity axis so as to produce a uniform peripheral speed, the molten metal stream will shape itself to the cylindrical surface in the same way as when laid upon a substantially flat moving surface and will wet and adhere to the surface, moving with it in the form of a continuously formed film or layer which is hydrostatically self-leveling. This layer or film is of substantially uniform section and of a thickness, which, within the limits heretofore mentioned, corresponds to the relative

velocity of flow of the stream and the peripheral or lineal velocity of the heat absorbing surface on which the stream is laid. That is to say, my procedure can be carried forward in the production of flat strip or sheet-like metal where the molten metal stream is delivered to or laid upon a cylindrical heat absorbing surface of a rotating element and the forces involved and the results accomplished are substantially the same as where the molten metal is laid upon a substantially flat moving surface as described in connection with Figs. 1 to 3.

The rotation involved, of course, occasions centrifugal force and it must therefore be noted that the annulus must be rotated at such a speed that the centrifugal force generated within the metal film or layer supported thereon is less than one pound per pound. In other words, the annulus must be so designed that the centrifugal force resulting from its rotation at the desired speed will not be the predominating force during the period that the molten metal is at a temperature above the solidification temperature.

All the forces heretofore mentioned in connection with the procedure as carried forward by apparatus, such as is illustrated in Fig. 1, are involved and, as previously stated, the force of adhesion of the molten metal film or layer to the heat absorbing surface is of considerable magnitude. As a matter of fact, it has been observed that a centrifugal force of 1000 pounds per pound opposing this adhesive force is not sufficient to lift the thin molten metal film away from the heat absorbing surface where that surface is clean at the time the molten metal is delivered thereto and is so moved as to avoid jolts or vibratory forces. It has also been observed that this adhesive force decreases rapidly as the temperature of the film decreases and approaches the freezing point of the metal and that the adhesive force plays no part after the film or layer has reached the freezing point and spontaneously crystallizes.

Upon reaching the solidification temperature, the film is actually separated from the heat absorbing surface, although it continues to travel at the same velocity as the surface, due to the fact that its particles have been accelerated to that velocity while in the liquid state. Upon solidification the centrifugal force freely lifts the continuously forming strip away from the heat absorbing surface if that force exceeds one pound per pound. From the foregoing it is apparent that the peripheral speed of the heat absorbing cylindrical surface is pre-

ferably such that the resulting centrifugal force, acting on the solidified product, is less than one pound per pound of film.

The object of employing a heat absorbing surface—whether cylindrical or plane—is: (1) to transform the stream of molten material, such as molten metal, into a hydrostatically self-leveling film of definite width and thickness; (2) to cool and chill this film into a solid flat product; and (3) to reduce the temperature of the solid film-like product to such a point below the solidification temperature as will facilitate delivery, collection, and the like.

Some advantage is gained by employing a rigid annulus rather than a flexible belt or band for the purpose of providing the heat absorbing surface. For example, the apparatus can be so designed that a large quantity of heat may be absorbed through the heat absorbing surface and by the heat absorbing material on which the surface is formed, without raising that material to such a temperature as will occasion erosion, mechanical distortion, heat cracking or pitting. It will, of course, be apparent that in order to accomplish this, the annulus, or at least the heat absorbing portion thereof, must be formed of high conductivity metal, such as copper, and its thickness must be such that no portion thereof will be raised above injurious temperature during the procedure of absorbing heat from the molten metal delivered thereto. I have found that it is desirable to employ such heat conducting metal and to so form the annulus that no portion thereof will be raised above 500° F. while carrying forward the procedure here under consideration. This involves the thickness of the heat absorbing rim or annulus onto which the molten metal is delivered and which, for want of a better term, may be termed "chilling plate."

Let it be assumed, for example, that it is desired to produce a continuous strip approximately one-fourth inch thick—i.e., about the maximum thickness that ordinary steel will adhere to the heat absorbing surface of a cold chilling plate and will cool uniformly throughout its thickness and when reaching the solidification point will spontaneously crystallize throughout its section and produce the desired crystalline structure. the quantity of heat involved under the assumed conditions is such that the so-called chilling plate must have a thickness of approximately one inch. It is commercially impractical, if not mechanically impossible, to bend a belt or band of

copper one inch in thickness around a pulley and at the same time so drive the belt as to provide a rapidly moving heat absorbing surface such as is here involved.

5 It will be apparent that even where such belt is made of copper or similar high conductivity metal, the pulleys would have to be of such enormous diameters and the belt of such enormous length  
10 as to render the whole procedure impractical.

Then too, by employing a rigid annulus the chilling plate can be water jacketed as shown and thus provide a convenient way of dissipating heat delivered thereto. Furthermore, an inner surface of the annulus may be employed as the heat absorbing surface. In this modification the molten metal receptacle is  
20 located interiorly of the annulus, for example at or adjacent the centre or axis thereof. Consequently, the molten metal is discharged through a nozzle onto the inner surface of the annulus. This  
25 annulus forms the product in less than a single revolution and can be readily cooled either by having the outer surface of the annulus dip into a cooling medium or alternatively water can be sprayed  
30 upon such surface. The formed product is stripped from the interior surface in much the same way as from the external surface in the preferred form, except that the stripper must necessarily turn the  
35 product through an angle so as to direct it angularly outwardly away from the annulus. The fact that the annulus is spokeless makes it possible to carry out the invention without undue complica-  
40 tions.

Fig. 5 is a diagrammatic view of apparatus somewhat similar to the apparatus disclosed in Fig. 4. It, however, diagrammatically discloses means  
45 for subjecting the layer or film of molten metal to a formative force after it has been formed on the surface of the heat absorbing annulus or chilling plate 40. The heat absorbing element 40 is of  
50 annular form and is so associated with a receptacle 6 and its delivery nozzle 5 that molten metal is laid onto the outer cylindrical surface 41 thereof, all as described in connection with Fig. 4. The  
55 annulus 40 is rotating at a high speed and the adhesive and other forces, acting on the stream of molten metal issuing from the nozzle 5, convert that stream into a film-like layer 35 which, as previously  
60 described, is hydrostatically self-leveling while the metal is in a molten and highly mobile condition. In addition, the film-like layer of molten metal adheres to the heat absorbing surface 41  
65 in such a way that it is possible to con-

sider the chilling plate (40) and the molten metal as a single bi-metallic section in determining the heat exchange conditions.

The roller 36a of Fig. 5 corresponds in structure and function to the roller 36 of Fig. 3, and is preferably water cooled as described in connection with the roller 36 so that it functions not only to exert a forming force on the film-like layer but  
70 also to absorb heat from the layer. The trunnions of the roller 36a are mounted in bearings 46, which are so mounted in an arcuate guide frame 47 that the roller may be shifted around the axis of the  
75 heat absorbing annulus 40 toward and away from the nozzle 5. In this way the roller may be moved toward and away from the point of initial contact of the molten metal with the heat absorbing  
80 surface and may be locked in the desired position. This adjustment of the position of the roller 36 peripherally of the annulus is accomplished by means, such as the set screws 47<sup>1</sup> forming a part of the  
85 apparatus diagrammatically illustrated in Fig. 5.

It will also be understood that the roller 36a is so rotated that its peripheral velocity equals that of the annulus 40,  
90 and that the roller 36a may be adjusted (by means not shown) to different positions radially of the annulus so as to vary the extent of the forming force applied to the film-like layer carried by the surface  
95 41 and appreciably reduce the section of the film-like layer as it passes under the roll or through the working pass formed by the cooperation of the annulus 40 and the roll.

In Fig. 5 I have also shown additional means for engaging and exerting force on the outer peripheral surface of the film-like layer or strip supported on the heat absorbing surface 41. These additional  
100 means are shown in the form of rollers 48, each of which is diagrammatically shown as trunnioned in a prong-shaped frame 49. Each frame 49 is indicated as pivotally mounted on a fulcrum shaft 51  
105 suitably carried by the frame of the apparatus and so arranged that each roller 48 is forced against the surface of the film-like strip passing under it. The rollers 48 may be of such weight or may  
110 be so arranged that one or more of them subjects the then formed hot metallic strip to a substantial deforming force, but I prefer to so adjust the rollers 48  
115 that the force exerted by each and the results accomplished thereby are similar to the force employed and the results accomplished in the usual planishing pass employed in rolling mill practice.

I have not intended to imply by either 130

Fig. 3 or Fig. 5 that the roll 36 or 36a is so located that it engages the surface of the film-like layer while the metal constituting that layer is still molten and highly mobile. While the heat transfer from the metal of the molten stream to the heat absorbing annulus 40 cannot be described accurately as instantaneous, nevertheless the conditions involved contribute to a very rapid dissipation of heat from the molten material and consequently the material loses its high mobility very rapidly as it is spread over the heat absorbing surface. It is, therefore, apparent that each infinitesimal section of the film-like layer moves through a relatively short arc around the center of rotation of the annulus 40, while passing from the highly liquid to the state at which it spontaneously crystallizes. The extent of this arc may be calculated more or less closely. I, however, note that under some conditions it may be desirable to position the roller 36 or 36a so that its surface does contact with molten metal. Under these conditions the roller plays an important part in abstracting latent heat from the molten metal and should, therefore, be formed of highly conductive material and preferably of material such as is wet by the molten metal involved. The wetting action, of course, involves adhesive and cohesive forces but, as previously stated, the roller is rotated at a relatively high speed, consequently the centrifugal force prevents any portion of the metal from sticking to the roller.

As the metal of the film-like layer is chilled below its point of spontaneous crystallization, contractive forces tend to and do free it from its contactual gripping engagement with the annulus 40, consequently it may be readily lifted from the heat absorbing surface and delivered as a continuously forming strip or sheet to a roller table or similar support. These contractive forces may also play some part in preventing the molten metal from adhering to the roller 36a when that roller is adjusted to such a position that it contacts with molten, as distinguished from plastic, metal.

In Fig. 5 I have diagrammatically illustrated the hood 23<sup>1</sup> as enclosing the roller 36a and also each of the rollers 48. My intent is to disclose that my improved process contemplates employing the desired atmosphere during those portions of the procedure in which a selected or controlled atmosphere may be beneficially employed.

Fig. 6 is likewise a diagrammatic view of apparatus which may be employed in carrying out my invention. In that view

the heat absorbing annulus 40 is shown broken away for convenience of illustration. It is associated with a receptacle 6a, which, like the receptacle 6<sup>1</sup> of Fig. 2 or Fig. 3, is provided with a metering valve 28a, so arranged that it may be adjusted toward and away from the stationary bottom wall 52 of the nozzle 5<sup>1</sup> and may also be driven at a predetermined speed for the purpose of aiding in the delivery of, or of actually propelling molten metal from the receptacle 6a and onto the heat absorbing element 40.

As shown, the feeding receptacle 6a is associated with a support shelf 53 forming a part of the frame of the machine and provided with free running rollers 55 and a single roller 56 for supporting the receptacle in different positions thereon. The single roller 56 is so located that when the receptacle 6a is filled with molten metal and is moved to an operative position, with relation to the annulus 40, it will be so supported on the roller 56 that it will balance toward the ring or annulus 40 causing the tip of the lower wall 52 of the metal delivery nozzle 5<sup>1</sup> to rub on the heat absorbing face of the annulus with a slight pressure. In this manner the molten metal stream issuing from the nozzle 5<sup>1</sup> will be laid gently upon the peripheral face of the annulus 40 without turbulence or splashing and the distribution of the metal peripherally of and across the face of the annulus 40 is as described in connection with Figs. 4 and 6. When it is desired to withdraw the receptacle 6a from operative relationship with the annulus 40 it is moved rearwardly along the shelf and is then supported by the rollers 55, as well as the roller 56.

In Fig. 6 I have indicated that the point of initial contact of the molten metal, issuing from the nozzle 5<sup>1</sup>, with the heat absorbing annulus 40 is substantially removed from the vertical axial plane of the annulus. The distance between this point and such plane, or the vertical diameter of the annulus is indicated by the letter X, thus disclosing that the adhesive and cohesive forces involved cause the molten metal to move, with the supporting, heat-absorbing surface of the annulus, and even though the initial movement is an upward movement. The distance X is not a fixed distance, but is to some extent determined by the desirability of so positioning the molten metal delivery nozzle, with relation to the annulus, that the stream of molten metal issuing therefrom will be laid upon the rapidly moving peripheral surface of the annulus with minimum

impact and turbulence.

In Fig. 7 I have shown the heat absorbing annulus or chilling ring 40 so mounted that it is not only capable of being rotated at the desired speed but also of properly cooperating with the molten-metal-feed receptacle 6 and of being free to expand and contract in response to the varying temperature conditions involved. As previously stated, the intent is to provide a heat absorbing annulus of such peripheral length that each heat absorbing portion thereof may be brought back to a preselected equalizing temperature of, for example, 300°, 400° or 500° F. between the time that it moves free of the finished product and again receives molten metal from the metal delivery nozzle. To comply with this requirement the ring or annulus 40 will necessarily be of large diameter and this accentuates the necessity for permitting free and unhampered expansion and contraction while driving the ring at the desired speed.

In the illustrated embodiment this condition is assured by supporting the annulus on spaced discs 57, which are carried on a shaft 58 of a roller bearing 59, of sufficient size to readily support the weight of the ring or annulus 40. (See also Fig. 8 and 11). The bearing 59 is rigidly secured to a lateral extension 60 of the frame of the machine. Each disc 57 is flanged as shown as 57<sup>1</sup> in Fig. 11 and is adapted to engage and support a re-entrant flange 61 forming a part of the annulus 40 (see Figs. 10 and 11). That is to say, the two discs 57 fit the two flanges 61 of the annulus in the same way that the flanged wheels of a rail traversing a vehicle fit the rails constituting the track, and the flanges 57<sup>1</sup> of the discs therefore laterally position the annulus.

In order to insure proper positioning of the annulus 40 during its rotation, I have provided two pairs of guiding discs 62 and 63 which are mounted on a frame 64 so arranged that it is free to move vertically and thus accommodate the free expansion and contraction of the annulus while imposing a guiding force on it.

The frame 64 is illustrated as substantially triangular. The mounting shaft 62<sup>1</sup> of the pair of discs 62 is journaled in a bearing 65 (preferably a roller bearing) located at one end of the base of the triangular frame 64. A similar construction and bearing is employed for the pair of discs 63 and the bearing 65<sup>1</sup>, forming a part of that assembly, is mounted at the other end of the base portion of the frame. An apex hub 66 is secured to the lateral members of the frame 64 and is so

formed that it receives a key shaft 67 rigidly secured to and depending from the shelf 60. This key shaft extends vertically and the apex hub is apertured to receive it. The relationship between the apex hub 66 and the shaft 67 is such that the hub is capable of sliding freely along the shaft, but is prevented from turning around the shaft.

The frame 64 is also provided with a base hub 68, which is secured to the base member of the triangular frame at a point midway between the bearings 65 and 65<sup>1</sup>. The base hub is apertured to receive an upwardly projecting shaft 69, which, as shown in Fig. 11, is rigidly secured to a bracket 69<sup>1</sup> of the main frame of the machine and is axially aligned with the key shaft 67. The shaft 69 is also a key shaft and the relationship between it and base hub 68 is such that the hub is capable of sliding freely along the shaft but is prevented from turning around it. Thus it is apparent that the cooperation between the key shaft 67 and the apex hub 66 and the cooperation between the key shaft 69 and the base hub 68 is such that the triangular frame is free to move vertically, but is prevented from swinging around the aligned shafts 67 and 69. The frame 64, therefore, provides a three point roller contact for each track flange 61 of the annulus 40. This arrangement of support for the annulus makes it possible to employ a centerless annulus or ring as the heat absorbing element and at the same time rotate that ring at the desired speed, but without occasioning side sway or swing during the rotation. That is to say, by employing the frame 64 and a mounting therefor, such as described, the annulus 40 may be rigidly guided while rotating but without hampering free expansion and contraction.

The weight of the frame 64 is substantially counter-balanced by weights 70. Fig. 11, acting through a counterbalancing lever 71, which is fulcrumed on a bracket 72 of the frame and is forked to provide a bifurcated end 73, which straddles an extended part of the hub 68 and engages a suitable collar formed thereon. The usual arrangement of counterbalancing weights is disclosed for the purpose of showing that the weight of the frame 64 and the associated parts may be more or less fully balanced.

A reference to Fig. 10 discloses that the centerless ring or annulus 40, there illustrated, is of H-section, i.e., the web portion 40<sub>w</sub> is provided with outwardly projecting flanges 75, as well as the re-entrant flanges 61. The flanges 75 define the width of the heat-absorbing,



molten-metal-receiving surface of the annulus 40 and while they are shown formed as a unitary part of the annulus, it is apparent that they may be separately formed and so arranged that they may be adjusted toward and away from each other so as to vary the effective width of this heat-absorbing surface.

Fig. 10 also discloses a convenient and desirable way of providing the web 40a with a water jacket or chamber 42<sup>1</sup> through which water or other coolant may be circulated. As there shown, the annulus is provided with an annular band of corrugated metal 76, which is fitted between and secured to the flanges 61 in such relationship to the web 40a as to provide an adequate cooling chamber or space. The lateral edges of the band are flanged and each such flanged edge is secured to one of the flanges 61 in such a way as to provide a water tight joint. In the apparatus illustrated this is accomplished by securing the flanged ends of the corrugated band 76 to the flanges 61 by means of short segmental sections 77 which are bolted to the flanges 61.

In Figs. 10 and 11, I have shown the inner face of the web 40a corrugated—i.e., provided with alternately arranged circumferentially extending grooves and ridges 78—for the purpose of providing an extended surface exposed to the coolant within the water jacket or chamber 42<sup>1</sup>. In Figs. 7, 8 and 11 I have illustrated means for obtaining a circulation of coolant through the chamber 42<sup>1</sup>. As there illustrated, the annulus 40 is provided with a manifold 79, to which a delivery pipe 80 is connected. The pipe 80 is also connected to an elbow 81 so located that its inlet leg is located centrally and extends axially of the annulus 40. A water delivery pipe 82 (Fig. 11) communicates with this elbow and is so connected to a source of water under pressure that it is capable of turning with the annulus, but at the same time supplying water to the chamber 42<sup>1</sup> through the inlet pipe 80. The annulus is also provided with an outlet manifold 93 and similar piping connections are associated with it so as to maintain a circulation throughout the annulus during its rotation. The inlet manifold 79 is separated from the outlet manifold 83 by a partition 84, which may extend entirely across the chamber 42<sup>1</sup>. An outlet pipe 85 communicates with and is secured to the outlet manifold 83 and is connected by suitable pipe connections 85—85<sup>1</sup> with a discharge pipe 86 (Fig. 11), which is located centrally and extends axially of the annulus 40.

It will, of course, be apparent that the

weight of the manifolds 79 and 83 and the associated piping must be counter-balanced or that inlet and outlet manifolds and delivery piping be so arranged around the annulus 40 as to avoid throwing it out of rotational balance.

In order to insure the free expansion and contraction of the annulus 40, I have provided a transmission gearing, which includes a centerless or ring gear 90 (Figs. 9 and 10), so mounted on the frame of the machine that it is located immediately adjacent the annulus 40 and is concentric therewith. By centerless gear, I mean one in the form of an annulus or ring and devoid of spokes and hub or equivalent structure. The ring gear 90 has a pitch diameter substantially equal to the diameter of the heat-absorbing cylindrical surface 41 of the annulus 40 and, as shown, its gear teeth are formed on its outer peripheral surface. The inner surface is provided with an annular ridge 91 which is shown as of rectangular section and is so located that it provides a roller-engaging track for the ring gear.

As shown in Figs. 9 and 11, the ring gear is supported by three spaced rollers 92, 93 and 94. The roller 92 is mounted on the shaft 58 of the roller bearing 59 and, like the other rollers 93 and 94, is peripherally grooved to receive the ridge of track 91. The rollers 93 and 94 are mounted on either side of the roller 92 and the three rollers are located in triangular relationship and in such positions, with relation to the circumferential track 91, as to definitely position the ring gear with relation to the frame of the machine. That is to say, the three point support defines the position of the axis of the ring gear and the cooperation of track ridge 91 and roller grooves defines the lateral position of the gear. Each of the rollers 93 and 94 is provided with a separate mounting shaft which is journaled in a separate bearing supported on and rigidly secured to the shelf 60 forming a part of the machine frame. With this arrangement, the ring gear 90 is provided with a three point support, thus definitely defining its position.

The gear 90 is driven by a motor 95, which is preferably of the variable speed type and is shown mounted on the shelf 60 of the frame. As shown in the drawings (Fig. 12) the shaft 95<sup>1</sup> of the motor is provided with a pinion 96, which meshes with and drives a gear 97, carried by a shaft 98 which also carries a pinion 99, which meshes with the teeth of the ring gear 90. The shaft 98 is mounted in a suitable bearing supported by a vertical wall 101, which forms a part of

the machine frame and projects vertically above the shelf 60. The pinion 99 meshes with the teeth of the ring gear and drives that gear.

- 5 As shown in Figs. 9 and 10, the ring gear 90 is provided with a plurality of laterally projecting pins 102, which are equally spaced in circular arrangement and cooperate with similarly located  
10 teeth 103 on the annulus 40 in providing a driving connection between the gear and annulus. As shown, the ring gear is provided with six such pins, each being threaded into an aperture provided for its  
15 reception and projecting laterally of the ring gear. The teeth 103 may be formed as an integral part of the annulus 40 and, as shown, each projects laterally from the outer lateral face of one of the flanges 61.  
20 It will, of course, be apparent that under the varying conditions of expansion and contraction, each such pin 102 and tooth 103 may not always be effective in transmitting power from the ring gear to the  
25 annulus, but each tooth and pin is so designed that it is capable of transmitting all of the power from the ring gear to the annulus.

- The frame of the machine must be of  
30 such section and dimensions as to provide a rigid support for the annulus, the ring gear and accessories. As illustrated, it is a cast structure and is, of course, intended to be rigidly secured to an  
35 adequate and rigid foundation. It consists essentially of a vertical wall member 104, which forms a support for the shelf 60, the brackets 69<sup>1</sup> and 72 heretofore mentioned and which also  
40 forms a rigid support for the so called vertical wall 101 which, as shown in Fig. 11, extends above the shelf 60 and is flanged at its upper end.

- Fig. 8 is a more or less diagrammatic  
45 elevation of the annulus 40, together with accessory apparatus. For convenience of illustration, a portion only of the machine frame is illustrated but it will be understood that the vertical wall portion of the  
50 frame is located in such relationship to the annulus 40 and the ring gear 90 that both may be rotated at high speeds without being subjected to substantial vibration, side sway, etc. In Fig. 8 I have dis-  
55 closed the molten metal feed receptacle 6 as provided with a separately formed removable delivery nozzle 105, which corresponds in function, location and structure to the previously described  
60 delivery nozzle 5 or 5<sup>1</sup>. The nozzle 105 is shown bolted to the metal casing of the receptacle 6 and a reference to previously described illustrations will make it  
65 receptacle itself, is lined with refractory

material and that its outlet is in such relationship with the molten metal receiving surface of the annulus 40 as to insure a non-turbulent delivery of molten metal onto that surface.

The apparatus illustrated in Fig. 8 is also provided with what has been heretofore termed a rotary metering valve, there designated by the numeral 106. As shown  
75 (Figs. 8 and 11), the metering valve 106 is in effect a water cooled roll provided with hollow trunnions 106<sup>1</sup>, which are suitably journaled in a yoke-shaped carriage 107 arranged to swing about a  
80 fulcrum shaft 108 and thus vary the position of the metering valve 106 with relation to the heat absorbing surface of the annulus 40.

The valve 106 is shown as formed in three parts, viz., a cylindrical part 109  
85 and two interlocking web portions 110 and 110<sup>1</sup>. Each of the previously mentioned hollow trunnions, 106<sup>1</sup> is shown formed as an integral part of one of the so called web portions. Each sub hub portion is  
90 peripherally flanged to receive the cylindrical portion 109 and the arrangement is such as to provide an interior chamber 111, which lies adjacent to the inner sur-  
95 face of the cylindrical part 109 and constitutes a cooling chamber for that part. Each rotary trunnion 106<sup>1</sup> is adapted to be included in a water circulating system for the chamber 111 and is, therefore,  
100 provided at its outer end with an ordinary fitting 112 which is secured thereto by means of a suitable packing gland nut 113 and which is provided with a suitable packing gland. As shown by the arrows  
105 in Fig. 11, cooling water or medium may be delivered to the trunnion 106<sup>1</sup> directly associated with the hub portion 110<sup>1</sup>. Radial passages 114 provide a means of communication between the interior of  
110 the trunnion and the chamber 111. Similar passages 114<sup>1</sup> are provided in the hub portion 110 and consequently form a means of communication between the chamber 111 and the hollow interior of the trunnion 106<sup>1</sup> directly associated with  
115 that hub portion.

The cylindrical part 109 of the rotary metering valve may be made of refractory material. On the other hand, it may be made of metal of high heat conductivity,  
120 in which case the inner face of the cylindrical portion will be preferably be corrugated as shown in Fig. 10 so as to present an extended area to the cooling chamber 111. Under such conditions, it will be  
125 desirable to continuously dissipate the heat absorbed by the metallic surface and this, of course, will be accomplished by providing a sufficient circulation of cooling medium through the chamber 111.

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As previously described, the molten metal contacting surface of the metering valve may be such as will be wet by the molten metal, but this surface is preferably oxidized or otherwise coated so as to prevent adhesion or sticking of the molten metal.

The fulcrum shaft 108 for the frame 107 is carried by the vertical wall portion 101 of the machine frame and the arrangement is such that movement of the frame 107 around the shaft 108 alters the relative position of the cylindrical surface of the part 109 with relation to the cylindrical surface 41 of the heat absorbing annulus. That is to say, the movable frame 107 provides means for adjusting the radial width of the space between the cylindrical face 41 of the annulus 40 and the peripheral face of the metering valve 106. This adjustment is accomplished by providing an adjustable abutment 115 for the free end of the fulcrum shaft 107. This abutment is shown in Figs. 8 and 9 as a pin threaded into a boss carried by the machine frame and projecting upwardly above the boss in such a position that it is engaged by the frame 107.

I have also shown means for counterbalancing at least a portion of the unsupported weight of the frame 107, the metering valve 106 and accessory to be described. As illustrated, this means consists of a crank cam 116 which is carried by a crank shaft 117 journaled in the vertical wall portion 101 of the machine frame. This crank shaft is geared to a counterweight spool by means of gears 119 and 120. The counterweight 121 is so supported by the spool 118 that the crank shaft 117 tends to turn in a counterclockwise direction, as shown in Figs. 8 and 9, and thus tends to counteract the turning moment imparted to the frame by the unsupported weight, etc. As shown in Fig. 9, the crank shaft 117 may be employed for the purpose of lifting the frame 107 and thus moving the metering valve to an inoperative position with relation to the annulus 40.

The metering valve 106 is provided with a driving gear 122 which, as shown, is in the form of a ring gear and is secured to the hub portion 110<sup>1</sup> (Fig. 11). Teeth of this gear 122 mesh with the teeth of the ring gear 90 when the frame 107 is in operative position with relation to the annulus 40, thus providing means for so driving the metering valve that the active peripheral surface thereof moves at the same peripheral velocity as that of the cooperating face of the annulus 40. As heretofore described, any suitable means may be employed for driving the metering valve and its position, with relation to

the molten metal delivery nozzle, may be such as heretofore described, particularly in connection with Fig. 3.

The apparatus of Fig. 8 is also shown as provided with a series of peripherally spaced rolls 123, each of which is mounted in a frame 124, fulcrumed to the vertical wall portion 101 of the machine frame. Each such frame 124 is pivotally mounted on a shaft, which is carried by the wall portion 101. Each such roller 123 is provided with an actuating gear 126, the teeth of which mesh with the teeth of the ring gear 90, thus providing means for driving the roll. As shown in Fig. 12, each roll 123 is hollow and is provided with means for establishing a continuous flow of cooling medium therethrough. This may be accomplished in a number of ways, but, as illustrated, the roll is provided with a hollow trunnion through which a water delivery pipe 127, Fig. 12, extends and which is provided with a suitable water discharge passage which surrounds this pipe and communicates with an outlet port. It will, of course, be understood that suitable gaskets and water delivery and discharge connections will be employed so as to insure water tight joints. These rolls 123 function as described in connection with the rolls 48 of Fig. 5, i.e., they hold the product in contact with the heat absorbing face 41 of the annulus, absorb heat from that product and they may be so arranged as to subject the product to a formative force.

In Figs. 8 and 12 I have shown brushes associated with active faces of the machine. For example, I preferably provide a brush 130 for engaging and sweeping the heat absorbing surface 41 of the annulus 40 just prior to the time that that surface moves under the molten metal delivery nozzle associated with it. The brush 130 is mounted on a suitably journaled shaft carried by the wall portion 101 of the machine frame. This shaft is provided with a pinion 131, which meshes with a gear 132, the teeth of which mesh with the teeth of the ring gear 90. The gear 132 is suitably journaled in bearings carried by the wall portion 101.

Similar brushes 133 and 134 are provided for the rotary metering valve 106. These brushes are shown journaled in an arc-shaped extension of the frame 107 and are driven, through the medium of separate pinions, by a gear 135 suitably mounted on the frame extension and in turn driven by the gear 122. These brushes function to not only remove dust and dirt from the associated surfaces but also such moisture as may collect thereon by reason of the fact that the surfaces in

question are water cooled or otherwise refrigerated.

For the purpose of insuring complete dissipation of such moisture I preferably employ brushes, such, for example, as carbon brushes, which yieldingly bear upon the refrigerated surfaces and thus insure dissipating the moisture before the surface contacts molten metal. For example, in Fig. 13, I have diagrammatically illustrated the metering valve 106 associated with a fragmental portion of the annulus 40 and of the receptacle 6. As there shown, the delivery end of the nozzle 105 bears on the heat-absorbing surface 41 and projects into the crotch formed between the effective surface of the metering valve 106 and the heat-absorbing surface 41, as well as into the channel formed by the lateral flanges 75 (Fig. 10). A carbon brush 136, Fig. 13, is mounted on the nozzle and yieldingly engages the cylindrical surface of the metering valve 106, i.e., it is held in position by a coil spring which acts between the brush and a lug 137 formed on the wall of the nozzle. It will be understood that the brush 136 extends clear across the active surface of the metering valve 106; that the active face of the brush is shaped to conform to the engaged surface of the metering valve; and that it, in effect, forms a seal between the nozzle and the metering valve and thus provides a substantially air tight space into which the molten metal is delivered.

I have shown a similar brush 136<sup>1</sup> located below the nozzle 106 and bearing on the heat-absorbing surface 41 of the annulus 40. Here, the brush is yieldingly held in position by means of a coil spring which acts between it and a lug 137<sup>1</sup> formed on or carried by the nozzle casing. Here again, the brush 136<sup>1</sup> extends clear across the face 41<sup>1</sup> and its face-engaging surface is such as to conform to the shape of the face 41 and the flanges 75. This brush also performs the double function of dissipating surface moisture and to some extent sealing the space into which molten metal is delivered by the nozzle.

As previously described the molten metal receptacle 6 may be shifted to different positions but, in order to establish a fixed relationship between the nozzle and the associated annulus 40 during the operation of the apparatus, I preferably provide an adjustable stop on the machine frame which may be moved to varying positions and which is adapted to be engaged by a pin carried by the receptacle 6. The pin may be locked to the stop, thus providing means for locking the receptacle in adjusted positions. It will be apparent that while the

receptacle 106, and corresponding receptacles illustrated throughout the various views, may be employed as integral parts of the apparatus here illustrated, these receptacles in effect disclose the necessity for employing a source of molten metal of controlled temperature. That is to say, the particular form of receptacles illustrated are not essential but they disclose the necessity for providing a source of temperature controlled molten metal and a means for laying a non-turbulent stream of such molten metal on a heat absorbing surface moving at a relatively high speed.

Previous description has disclosed the necessity for accurate control of temperature conditions within the stream of molten metal as it is laid upon the heat-absorbing surface. That is to say, temperature conditions must be such that while rapid heat dissipation is encountered and is desirable, immediately upon contact between the stream and the heat-absorbing surface, nevertheless the time element must be such that the stream is distributed over the heat-absorbing surface and leveled to the desired thickness before the solidification temperature is reached. It is, therefore, desirable to control the temperature of the molten metal at the source of supply for the purpose of insuring desirable temperature conditions at the outlet of the delivery nozzle and to this end I have diagrammatically shown a gas or oil burner 140 associated with the fragmental view of the receptacle 6 in Fig. 13. It will be apparent to those skilled in the art that a single burner of this character will hardly be effective in connection with conditions such as are necessarily encountered where a molten metal distributing receptacle, such as the receptacle 6, is employed, but the illustration discloses the necessity or at least the desirability of controlling heat input and thus controlling the temperature of the metal as it arrives at the delivery end of the nozzle 105.

In connection with previously described apparatus, I have noted that the heat-absorbing surface is preferably polished and under some conditions plated. It will, of course, be understood that similar provisions are contemplated in connection with the heat-absorbing surface 41 of the annulus, particularly where the annulus is constructed of metal having a high heat conductivity, such as copper or some copper alloys. It, therefore, should be stated that I contemplate providing the surface 41 as well as the inner faces of the flanges 75 (Fig. 10) with a protective coating, such as a coating of chromium, tungsten or molybdenum. This coating

may be applied in any suitable manner which will provide an adequate bond between it and the coated metal. That is to say, electro-plating may be resorted to provided some additional procedure is employed which insures a bonding or a fusion between plated and the plating metal.

While high temperatures are involved in connection with my procedure and while steam may, therefore, be generated in some of the water cooling chambers, particularly if the water supply is reduced or momentarily stopped, nevertheless I have not disclosed these cooling chambers as provided with relief or safety valves. This, however, is because I contemplate providing discharge passages of such area that they will insure the delivery of steam at least in such quantities as will prevent the building up of objectionable steam pressure within the cooling chamber. Where conditions are such that restricted passages are necessary, then adequate safety or relief valves should be provided to prevent the accidental blowing up of the cooling chamber.

Referring now to Fig. 14, there is therein illustrated an apparatus characterized in that two distinct molten metals or substances are mechanically fed by a metering valve in two contiguous streams upon a cooling belt or cooling section. These two molten streams are deposited in non-turbulent condition side by side and the strips or films subsequently formed are united at their edges to produce a bimetallic strip having longitudinal bands of different metals. The double-compartmented receptacle 210 has a chamber 211 into which molten metal is poured, a port 212 in partition 213 and through which the molten metal flows free of slag into chamber 214 from which it then flows through outlet 215 under metering cylinder 216 to be laid upon moving belt 217 running in grooved guides 218 which causes it to assume the form of a film or strip 219.

The receptacle 210 has a contiguous but separated chamber 220 into which another molten metal is poured simultaneously, port 221 through which it flows into chamber 222 free of slag and from which it flows through outlet 223 under metering cylinder 216 which controls the stream upon moving belt 217, thinning it and converting it into film or strip 224. The outlets 215 and 223 are shaped so that their streams will merge at 225 when propelled by metering cylinder valve 216. The belt 217 consequently carries a single film or strip formed of two distinct metals, mixed and bonded at their contiguous edge, of preselected width and thickness

and of a total width 226 which is also preselected.

At the point where this bimetallic film has lost enough heat by conduction to belt 217 so that it is still plastic but has a part of the solid phase precipitated, the water-cooled forming roll 227 is adjusted to press upon this film to reduce its thickness and while doing so expands the width of the film 224 to square it against the straight edge of rim 228 of this roll and expands the opposite edge of film 219 against toothed rim 229 of the same roll 227 so as to mold that edge in the shape of saw teeth 217a or any other desired shape. Furthermore, the face of roll 227 can be set out of parallel (inclined) with respect to the surface of the belt 217 and the metal film it carries so that the flat solid product will be wedge-shaped, as shown in Fig. 14a, this being a very desirable section for saw blades or other products. Furthermore, the tooth-edge band or strip 219 can be made of a good cutting steel alloy, such as high speed steel, and the other band or strip 224 of a strong and tough alloy steel, such as chrome vanadium steel. As 219 and 224 merge and unite the strongest possible bond and union of these two alloy steels is effected as they readily mix at their edge in the molten state, free of any oxidizing agent or fluxing material and both solidify substantially simultaneously. Similar arrangements with various molten metals can be produced for various commercial purposes. This whole operation can be carried out under an air-tight hood, in a vacuum or in any special or desired atmosphere of stagnant or circulated preselected gases.

It will, moreover, be observed from Fig. 14 that roll 227 is rotatably mounted in bearings 230 in which hollow trunnions or the like 231 turn. The hollow trunnions communicate with a passage 232 in the roll 227 via openings 233 in members 228 and 229. A coolant, such as water, enters an intake 234 and leaves via the outlet 235, suitable connections being made at the trunnion ends to permit relative rotation. This cooling prevents undesired heating or rise in temperature of roll 227. One trunnion 231 has a gear 236 secured thereto which is driven or rotated at requisite speed by any suitable associated equipment (not shown).

Fig. 15 is a modification of Fig. 14 in that two or more streams of molten metal are laid in successive superimposed layers on the chilling belt or section instead of side by side. This view shows a molten metal receptacle 237 with a metering cylinder valve 238 like that (216) described above, which lays on belt 241 a

stream of molten metal 239 of preselected and controlled width and thickness from the body of molten metal 240 in receptacle 237. Stream 239 is supplied at a definite rate of flow as controlled by the metering valve. This stream 239 is thinned down and carried by moving belt 241 in the form of a film or strip 242 of uniform width and thickness. This film cools down under known conditions by transfer of heat to belt 241; hence, a definite temperature convenient for proper bonding with another metal film or strip can be secured by predetermining the length of contact, e.g., that designated by distance 243, which will produce this temperature. This contact length can be mathematically calculated. At this point a stream 244 of another or different metal 245 supplied from receptacle 246 by metering cylinder valve 247 is supplied and deposited over the film 242 to form another superimposed film 248 by the same wetting action already described. Film 248 may be of the same or different width, as it may be desired to cover only part of the surface of film 242, and of a preselected thickness as controlled by the rate of flow of molten metal 245 propelled by metering valve 247 and the velocity of belt 241 and film 242 adhered to it.

From such point, the belt 241 carries two superimposed metallic films which can be submitted to the action of forming roll when reaching a preselected temperature, and the whole operation can be carried under an air-tight hood, in a vacuum or in any desired stagnant or circulating gaseous atmosphere so as to keep a clean unoxidized film surface to properly unite the metal of film 242 with it. By proper selection of the metal used, thickness of film, and temperature of first film when the second one is formed upon it, many metals or alloys can be united to form bimetallic strips and the bond and union between the two superimposed layers made very effective. Three or more layers can be also formed in the same manner to obtain specific multimetallic, flat, solid products.

Instead of another molten metal or alloy, the receptacle 246 with metering valve 247 can be used to mechanically distribute over the surface of film 242 a layer of finely powdered material, such as ferrochrome, to mix and combine, for instance, with a molten film of ordinary steel and give the solid, flat product an alloyed surface resisting heat and corrosion; or pulverized ferro-manganese to make the surface wear and abrasion resisting, or any of the hard facing powdered materials such as boron crystals or others, or diamond powder can be em-

bedded in the whole width or part of it to make special tools. Also metallic powder, such as aluminium, copper, brass, etc., can be mechanically distributed so as to fuse over the surface of the molten metal film which subsequently is subjected to the action of a forming roll to embed any one or a combination of the above materials into the carried metal film and at the same time to smooth or shape its top surface. Furthermore, by providing the forming roll with a grooved or corrugated surface, grooves or corrugations 249 can be reproduced and molded in the solid flat product 250 as illustrated in Fig. 16. In this same manner other different shapes, impressions or irregularities can be reproduced such as serrations, corrugations, markings, dividing lines, embossed contours, etc.

Fig. 17 illustrates a variation of the apparatus of Figs. 14 and 15 in that it is adapted to make ply-metal flat products. In this form of the invention, the molten metal stream 251 discharging from receptacle 252 is formed into and carried as a metal film 253 by belt 254. Forming roll 255 is set so that a solid strip or sheet 256 of another metal unrolling from coil 257 will press down over the metal film 253 under a controlled pressure. The distance from nozzle 258 at which the roll 255 is set is so calculated so that the metal film 253, when reaching that point, has lost enough heat by conduction to belt 254 to be still liquid but has part of its solid phase precipitated so that it will wet the strip 256 pressed over it under roll 255 and will bind and unite with this solid strip to form a ply-metal flat product.

Referring further to Fig. 17 the belt 254 is an endless belt of suitable metal passing around wheels or pulleys 259 either of which is suitably driven. The surface of belt 254 which contacts the film 253 is preferably of such nature as to impart a smooth surface to such film.

Receptacle 252 is preferably in the form of a metal container 260 having a refractory lining 261. A partition 262 is provided with a port 263 so that molten metal free of slag can be discharged through nozzle 258.

Solid strip 256 is preheated prior to contact with strip 253. This is accomplished by mounting an electric or other heating device 264 in such manner as to form a sealed chamber 265 to prevent oxidation of strip 253. By means of an aperture or pipe 266 any desired active or inert gaseous atmosphere may be maintained in chamber 265 either stagnant or circulated. Whatever the precise form of heating device 264, strip 256 passes there-through and is raised to the desired tem-



perature which depends on the particular composition of strip 256.

The composite strip may be formed into a coil around core or wheel 267 and in such strip at least the strip 253 has the primary crystal structure above referred. Strip 256 may be one made by the present procedure and in such has a similar crystal structure.

The microstructure of the products which I produce in accordance with the present invention is well illustrated in Figs. 18 and 19. Both figures show the unusual uniformity, homogeneity and purity of the products, the unoriented nature of the crystal structure and the small stringer-like crystal form. Absence of the usual segregation and heterogeneity can be particularly noted from the photomicrographs. Comparison with ordinary conventional structures emphasizes the new and unique character of the microstructure of my products.

It will be understood that various modifications may be made in the arrangements described without departing from the scope of the invention.

Having now particularly described and ascertained the nature of my said invention, and in what manner the same is to be performed, I declare that what I claim is:—

1. In the manufacture of flat metallic products by discharging molten metal as a stream, converting the same into a strip, rapidly undercooling said strip substantially uniformly throughout its entire cross section down to a metastable state at a predetermined temperature below but close to the freezing point of the metal, and causing the strip to crystallize spontaneously throughout from said metastable state, the use of apparatus comprising the combination of means for discharging said molten metal as a stream, means for converting the same into a strip, means for undercooling the same to said predetermined temperature and for causing the strip to crystallize spontaneously.

2. In the manufacture of flat metallic products by discharging molten metal as a stream, converting the same into a strip, rapidly undercooling said strip substantially uniformly throughout its entire cross section down to a metastable state at a predetermined temperature below but close to the freezing point of the metal, and causing the strip to crystallize spontaneously throughout from said metastable state, the use of apparatus comprising the combination of means for continuously and uniformly flowing the molten metal through an orifice directly onto a flat or curved heat conducting sur-

face, means for moving said surface at uniform velocity away from said orifice to draw out said metal into a strip moving therewith, means for maintaining said surface at a temperature such that it rapidly undercools said strip substantially uniformly throughout its entire cross section down to said predetermined temperature and causes the strip to crystallize spontaneously throughout from said metastable state, and means for continuously removing the solidified strip from said surface.

3. Apparatus for making a flat metallic product which comprises means for continuously and uniformly flowing molten metal through an orifice directly onto a flat or curved heat conducting surface, means for moving said surface at uniform velocity away from said orifice so that said metal is drawn out into a strip moving therewith, and means for maintaining said surface at a temperature such that it rapidly cools the said strip as it is formed on the surface to a predetermined temperature below the solidification point of the metal, means being provided for continuously removing the solidified strip from said surface.

4. Apparatus according to claim 1, 2 or 3 including means for providing the strip with a protective atmosphere until it is fully solidified.

5. Apparatus according to any of claims 2 to 4 in which the molten metal is flowed from a container having an orifice at the bottom thereof located adjacent said surface.

6. Apparatus according to claim 5 including means for providing a non-turbulent discharge of metal through said orifice.

7. Apparatus according to claim 5 including a device within said container for regulating the rate of flow of metal therefrom.

8. Apparatus according to any of claims 2 to 7 including means for ensuring a substantially uniform flow of metal onto said surface throughout all portions of the stream.

9. Apparatus according to claim 8 in which said means comprises a rotatable and preferably cooled metering valve adjacent the region of initial contact of the molten metal with the moving surface, said valve having its periphery parallel to said surface.

10. Apparatus according to any of claims 2 to 9 in which said surface is of such nature that the molten metal wets the same.

11. Apparatus according to any of claims 2 to 10, including one or more forming rolls, preferably driven at the

same speed as said moving surface, and adapted to contact with controlled pressure against the upper surface of the formed strip of metal.

5 12. Apparatus according to any of claims 2 to 11 in which a curved surface is employed and the metal is flowed thereon in a region where said surface is ascending.

10 13. Apparatus according to any of claims 2 to 11 in which said surface is in the form of an annulus providing an uninterrupted, substantially uniform, peripheral surface, said annulus being  
15 mounted so as to permit free expansion and contraction thereof.

14. Apparatus according to any of claims 2 to 13, comprising means for flowing a plurality of portions of metal  
20 of different composition onto said surface to form a plurality of longitudinally adjacent strips.

15. Apparatus according to any of claims 2 to 13, comprising means for  
25 flowing molten metal of different composition onto the upper side of the strip formed on said surface adjacent the region of formation of the latter.

16. Apparatus according to any of  
30 claims 2 to 13, comprising means for pressing a strip of solid metal of different composition into contact with the upper side of the strip formed on said surface adjacent the region of formation of the

latter.

17. Apparatus according to any of the preceding claims, including means for imparting a wedge shaped cross section to the product prior to complete solidifica-  
35 tion.

18. Apparatus according to any of the preceding claims, including means for contouring, e.g. serrating, a longitudinal marginal edge of the product prior to  
40 complete solidification.

19. Apparatus according to any of the preceding claims, including means for imparting predetermined surface contours to the product prior to complete solidifica-  
45 tion.

20. Apparatus for making a flat metallic product substantially as herein-  
50 before described.

Dated this 22nd day of August, 1938.

For: JOSEPH MARCEL MERLE,  
Stevens, Langner, Parry & Rollinson,  
Chartered Patent Agents,  
5—9, Quality Court,  
Chancery Lane, London, W.C.2,  
and at  
120, East 41st Street,  
New York, U.S.A.

Reference has been directed, in pursuance of Section 7, sub-section (4), of the Patents and Designs Acts, 1907 to 1939, to Specifications No. 25125/13, 15548/13, 24320/09, 6630/07 and 6464/1890.

[This Drawing is a reproduction of the Original on a reduced scale.]

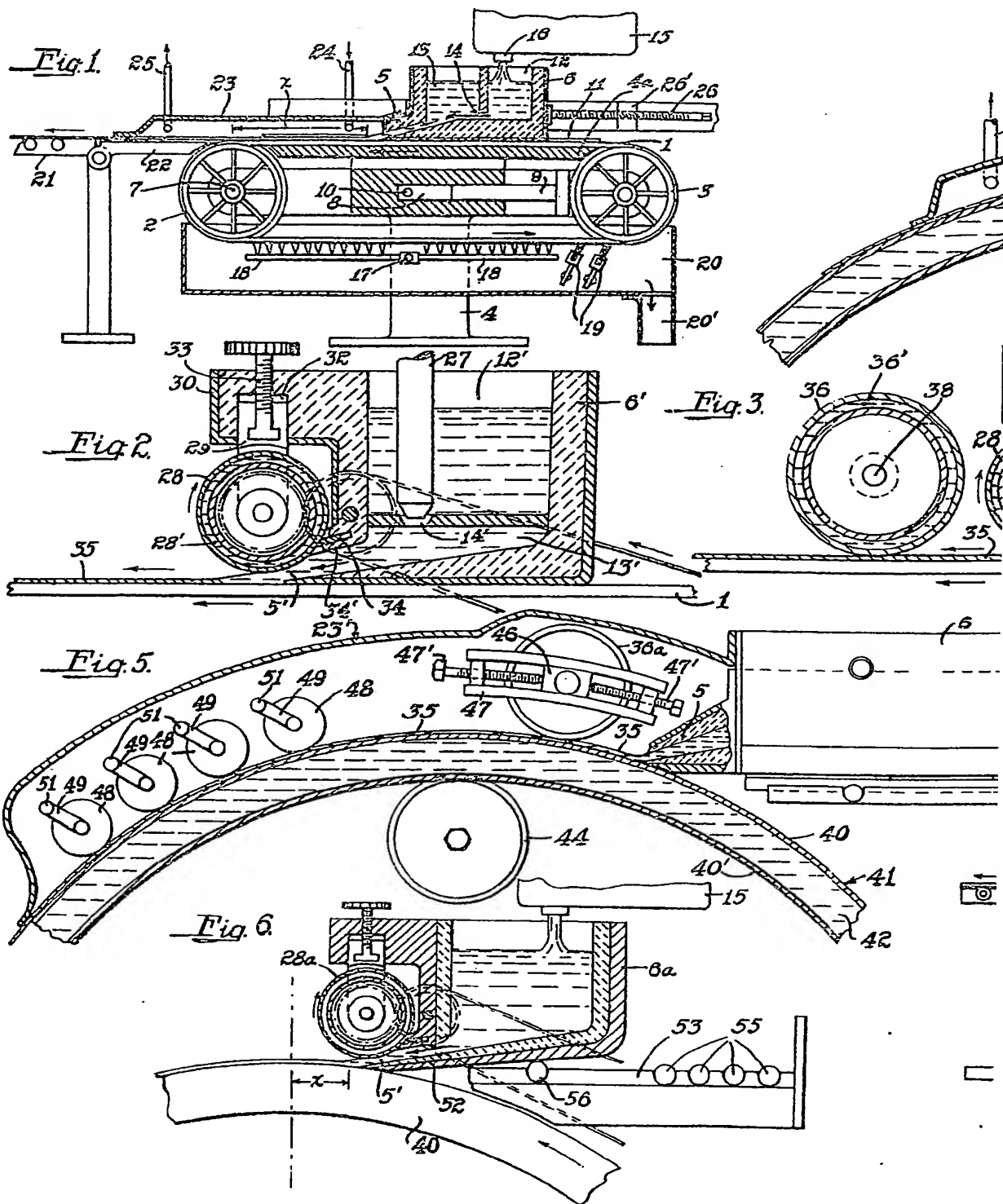


Fig. 4.

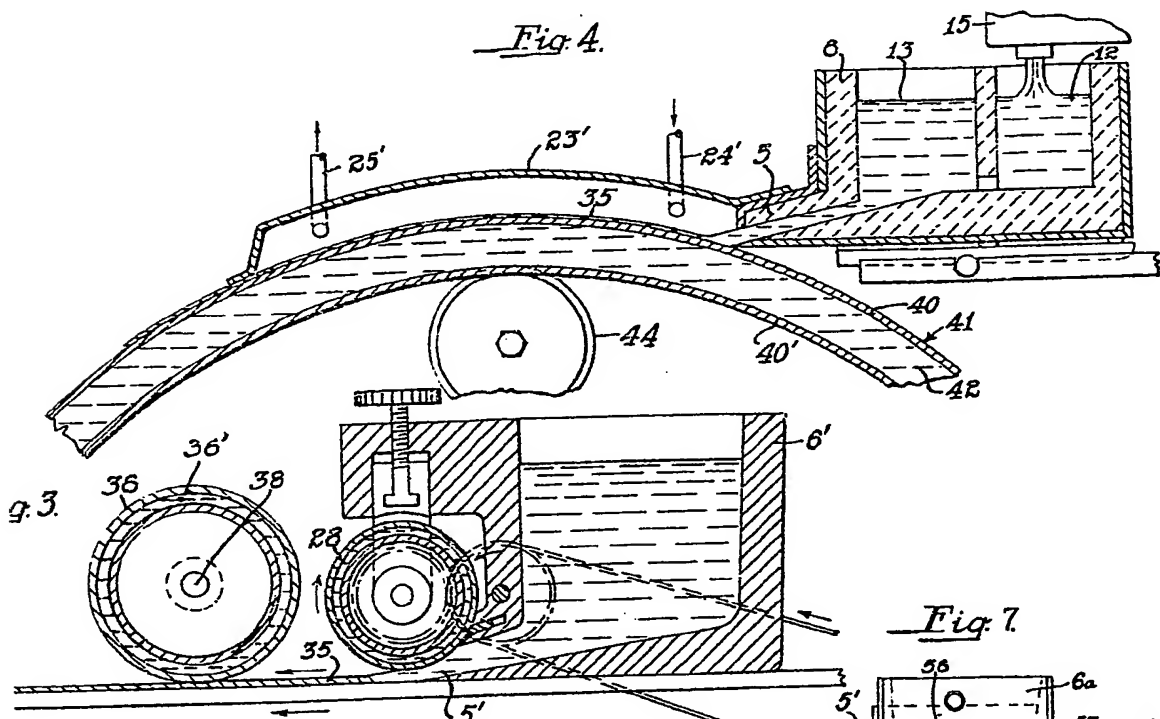
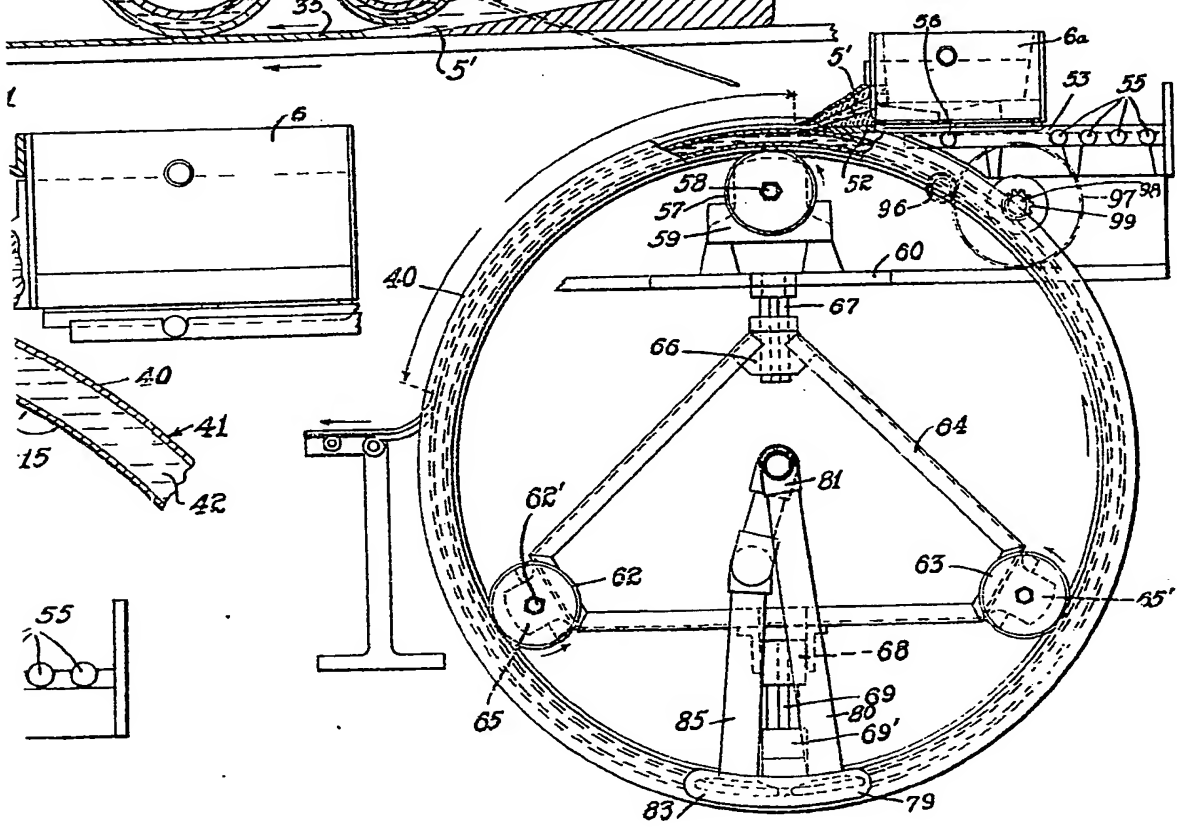
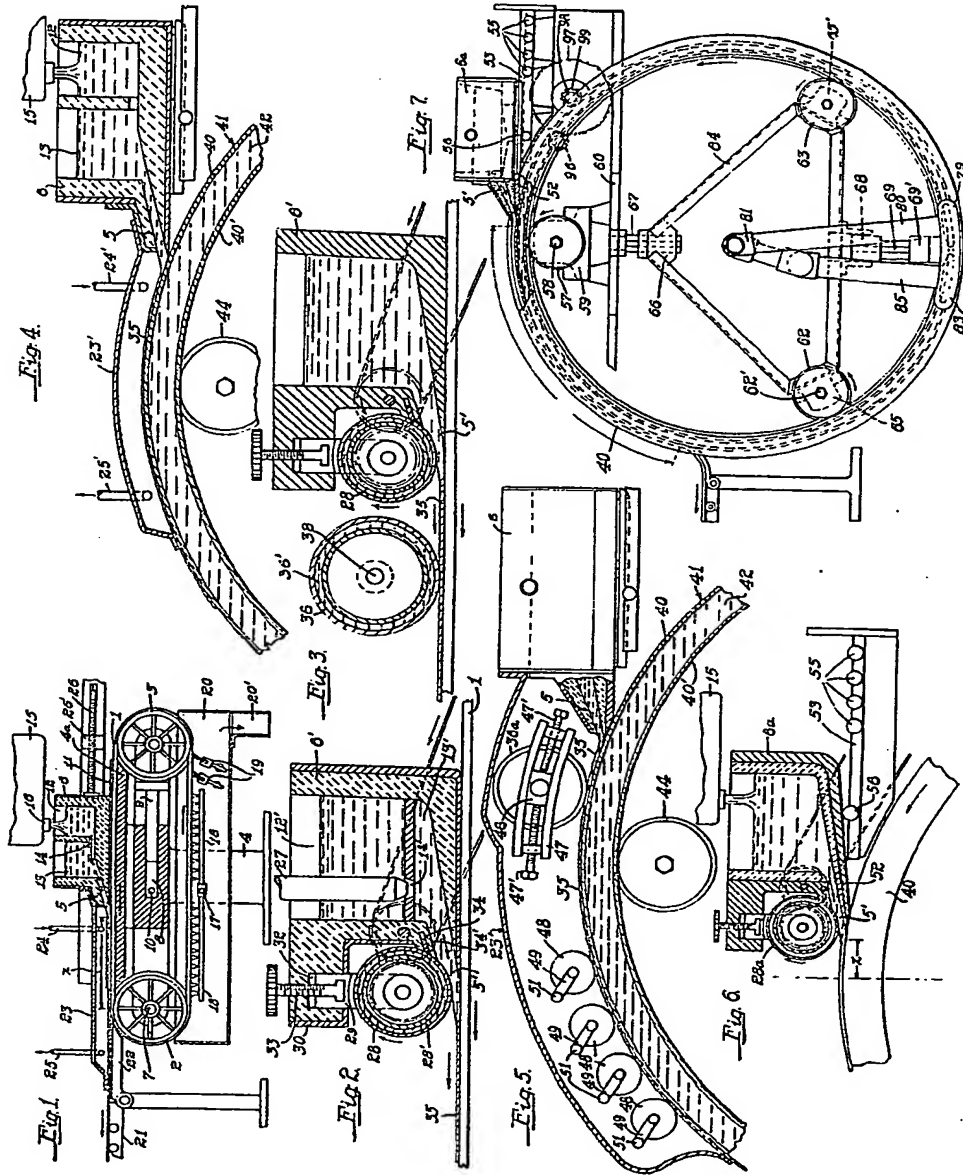
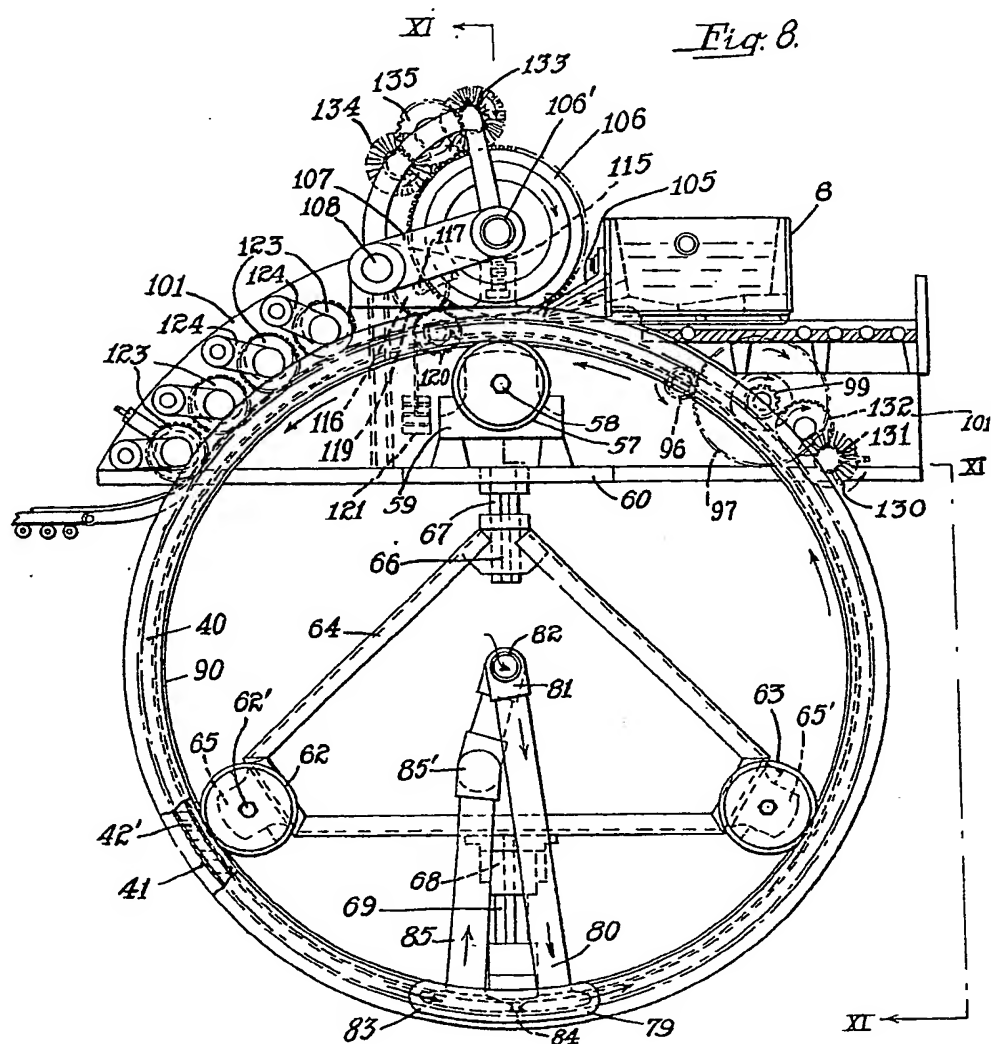


Fig. 7.

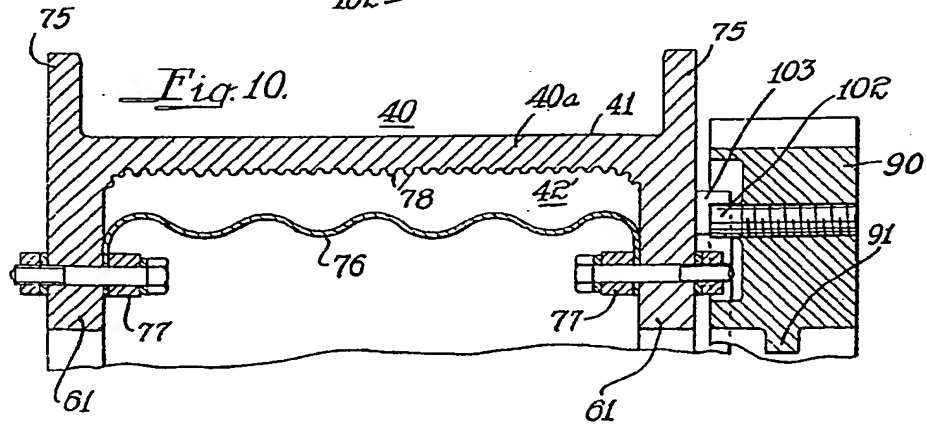
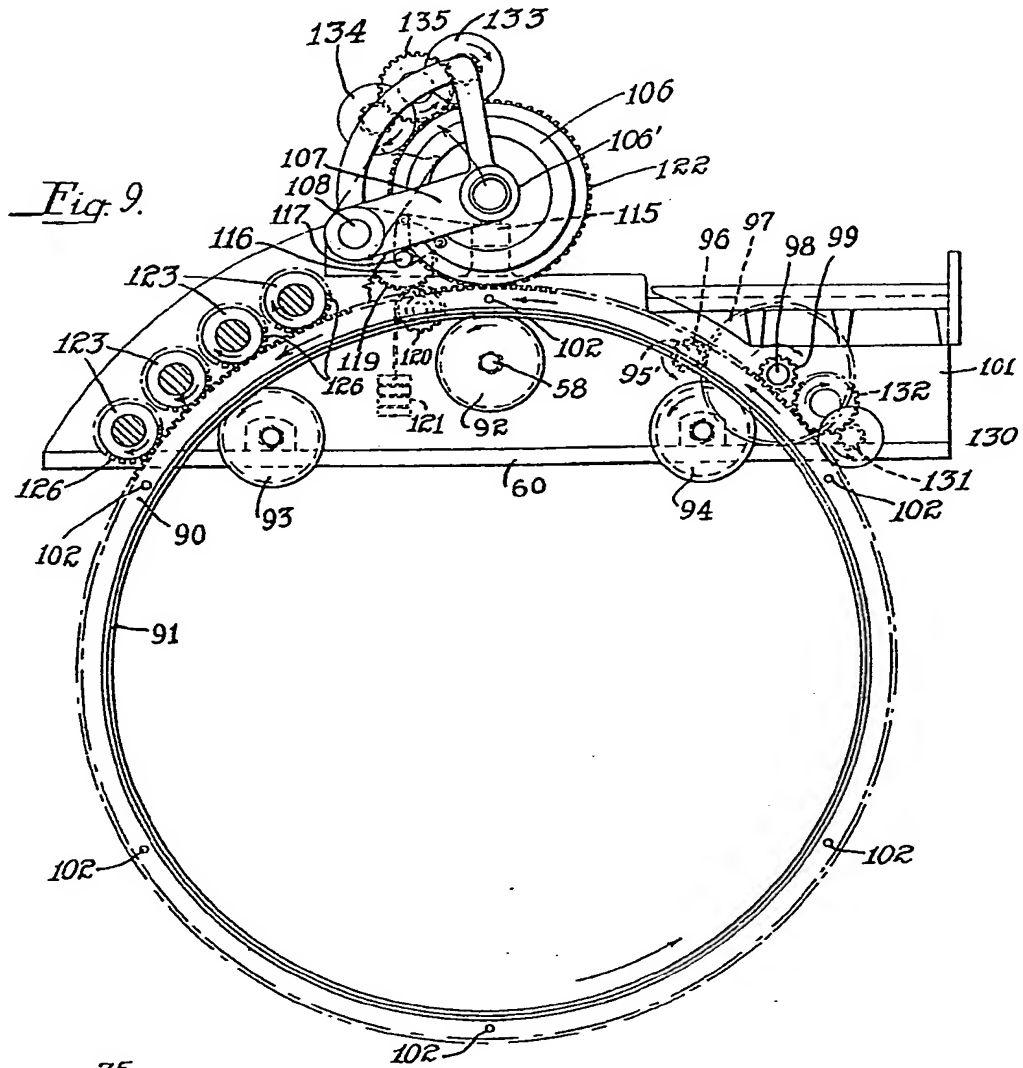


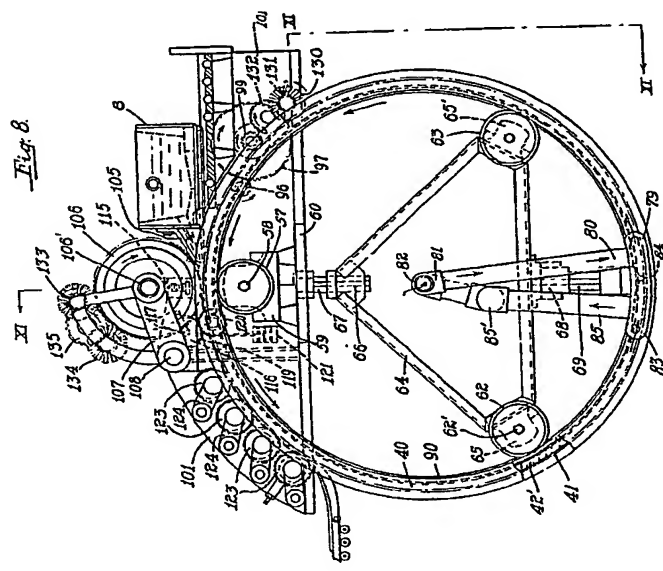
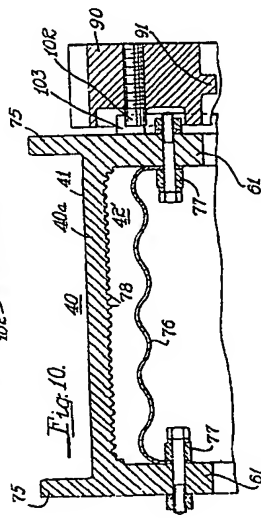
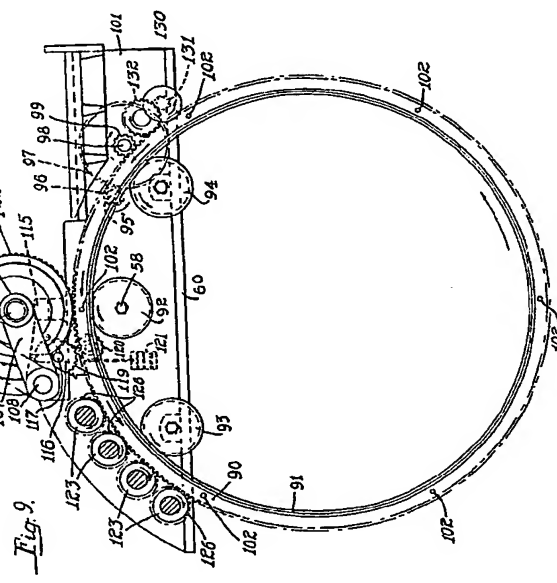
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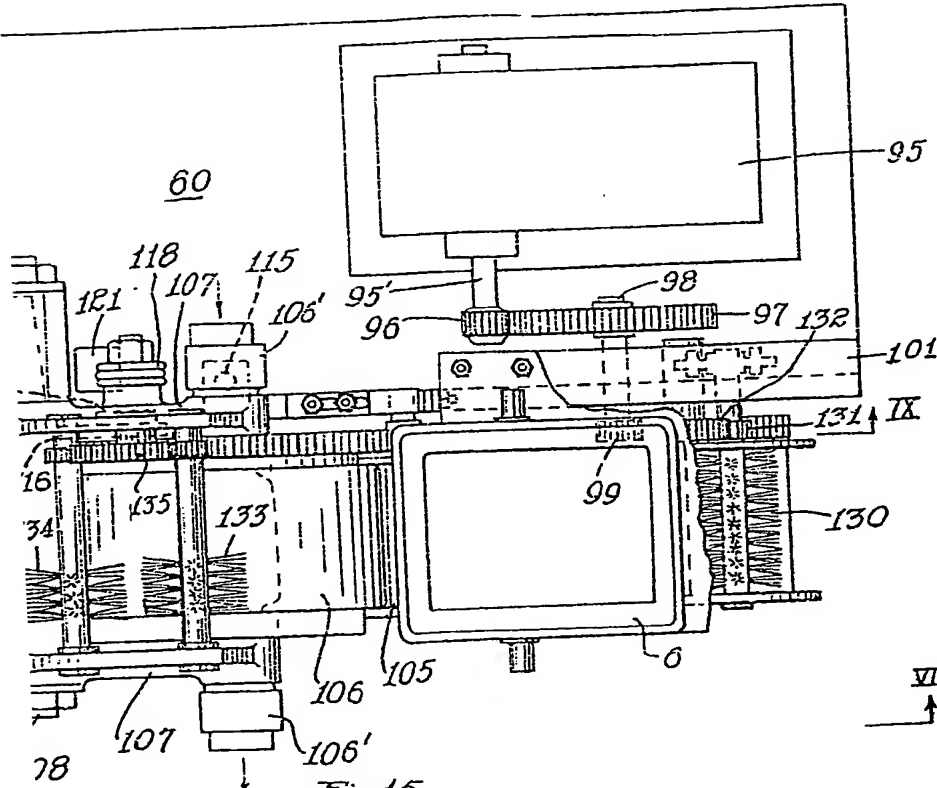


Fig. 15.

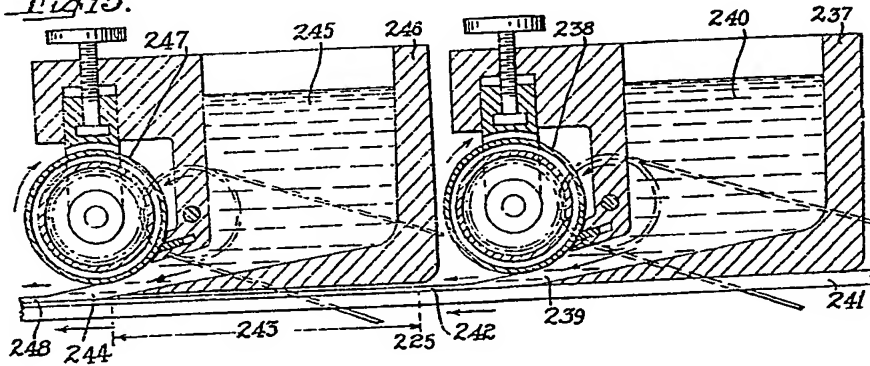
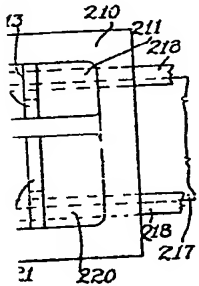


Fig. 14.

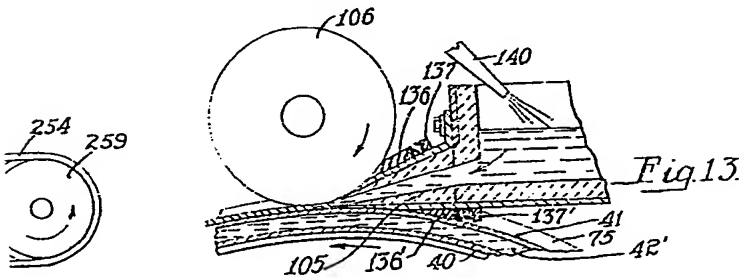


Fig. 13.

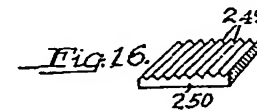
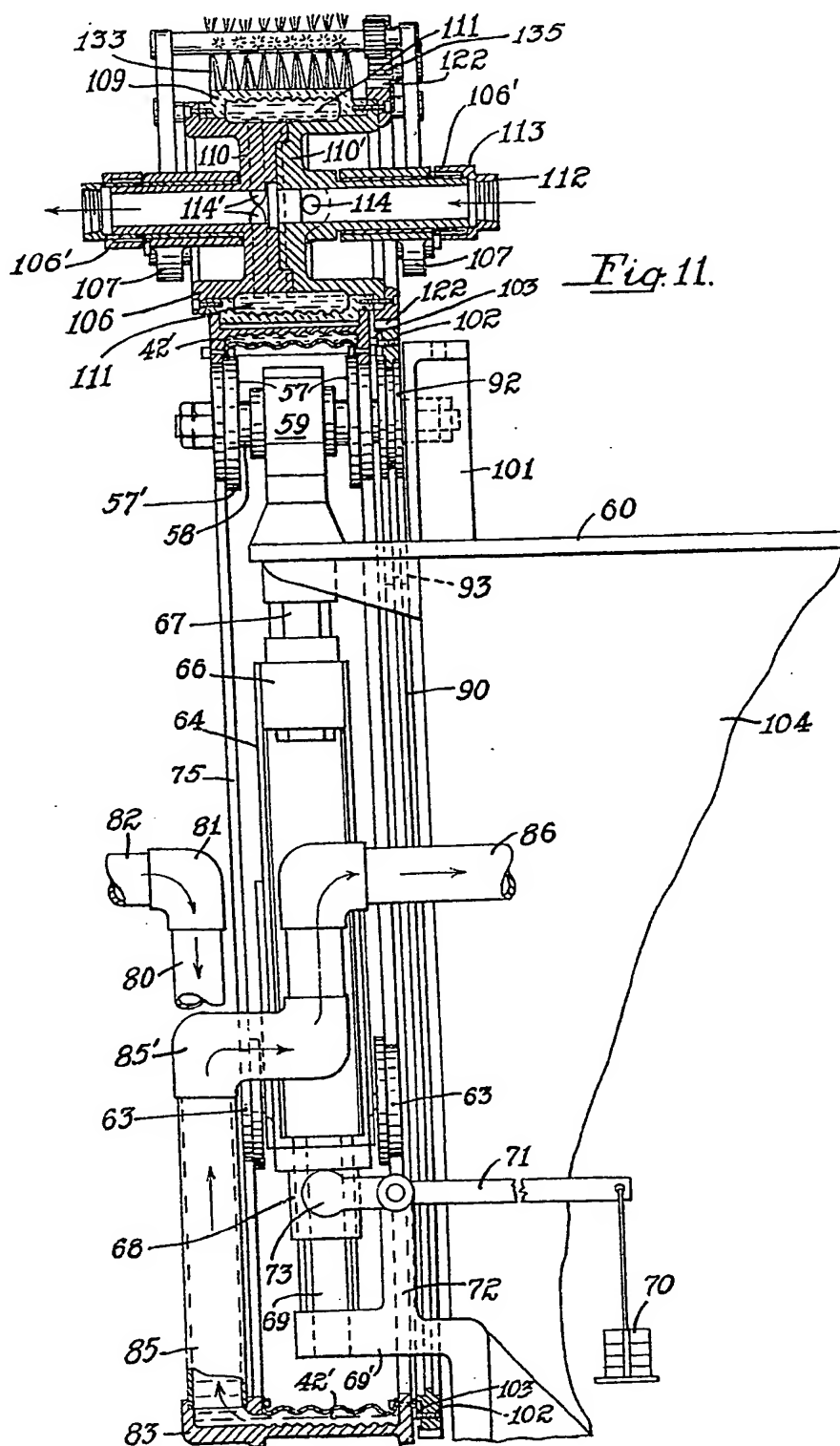


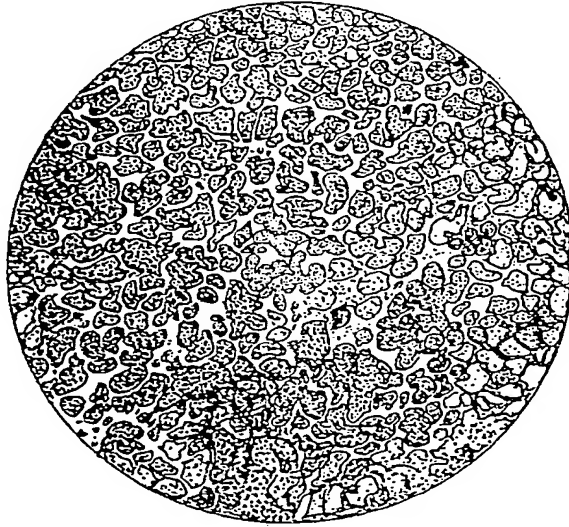
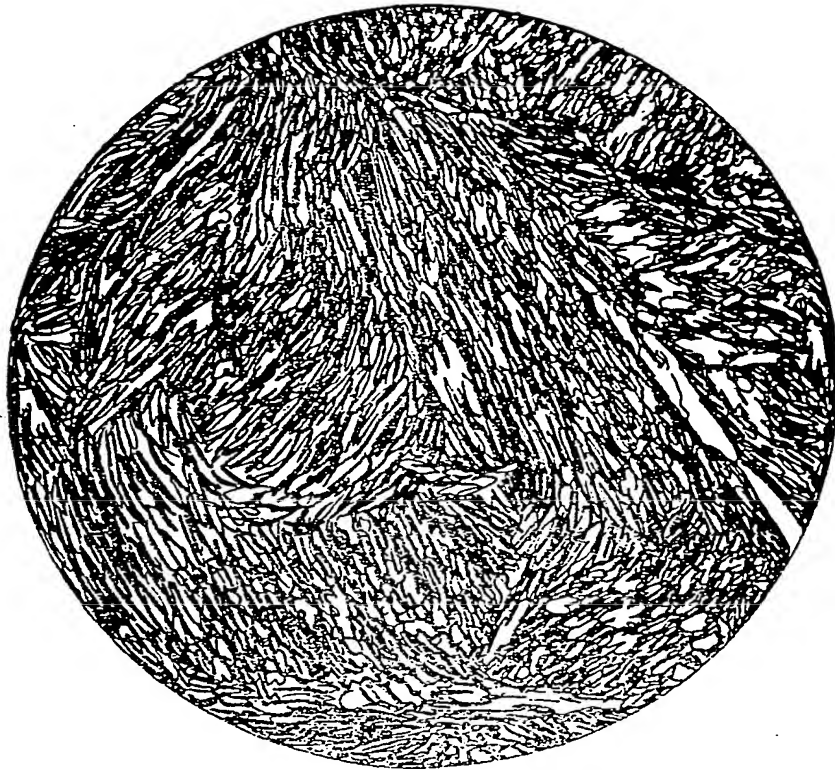
Fig. 16.





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Fig. 18.Fig. 19.

519,978 COMPLETE SPECIFICATION

SHEET 4

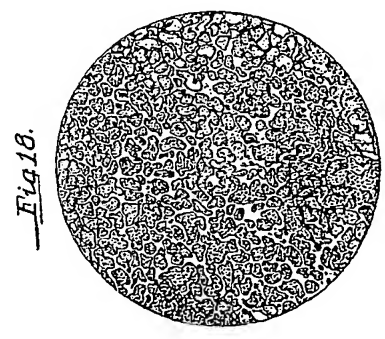
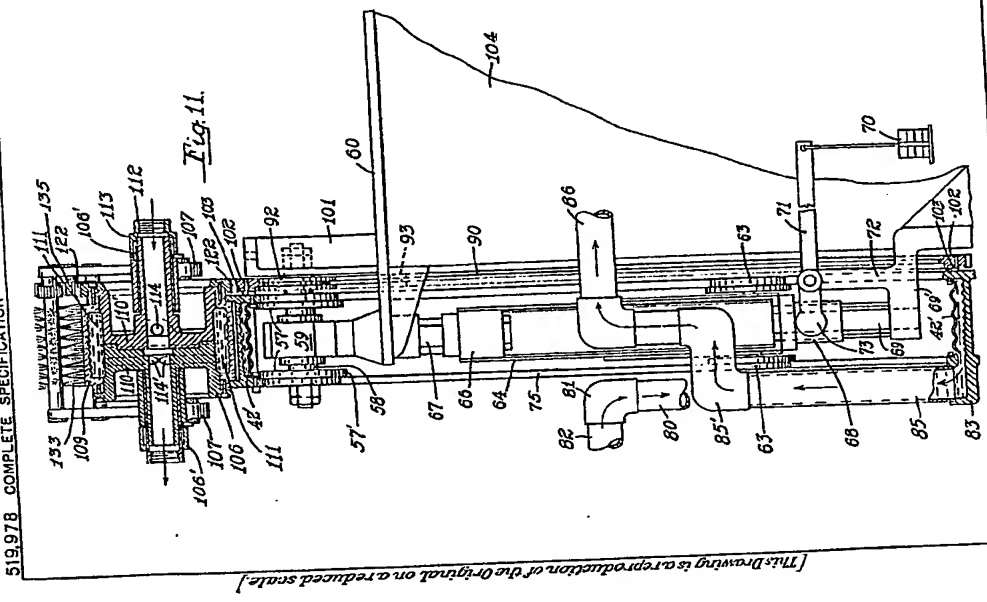
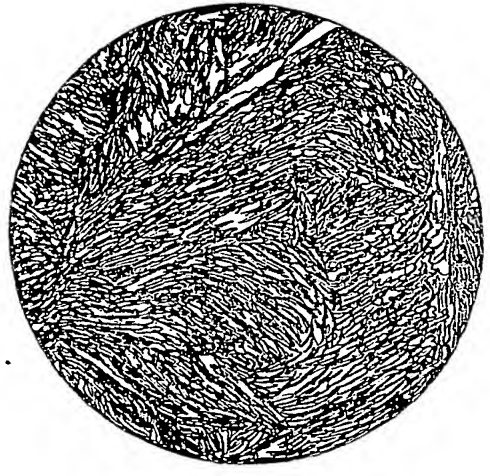


Fig. 19.



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